

WE CLAIM:

1           1.       A method for obtaining a relatively high dynamic range image of a scene using a  
2 relatively low dynamic range image sensor exposed to incident light from the scene for capturing  
3 an image thereof, the image sensor having a multiplicity of light-sensing elements in an array,  
4 each light-sensing element having a particular one of a plurality of sensitivity levels to incident  
5 light in accordance with a predetermined sensitivity pattern for the array of light-sensing  
6 elements and having a response function, each light-sensing element being responsive to incident  
7 light from the scene for producing a captured image brightness value at a corresponding one of a  
8 multiplicity of pixel positions of a pixel position array, whereby each one of the multiplicity of  
9 pixel positions corresponds to a particular one of the plurality of sensitivity levels of the light-  
10 sensing elements, the method comprising the steps of:

11               (a) estimating respective off-grid brightness values at a multiplicity of off-grid positions  
12 from respective captured image brightness values at pixel positions of the pixel position array,  
13 the off-grid positions being located at respective interstices of the pixel position array and  
14 forming a regular off-grid position array; and

15               (b) deriving pixel brightness values of an output image from the estimated off-grid  
16 brightness values.

1           2. The method of claim 1, wherein the array of light-sensing elements of the image sensor  
2 is a linear array for capturing a line image, and the pixel position array is a linear array having

the multiplicity of pixel positions at respective regularly spaced pixel positions in a pixel row so as to define a linear captured image brightness value array.

3. The method of claim 1, wherein the array of light-sensing elements of the image sensor is a linear array and the pixel position array is a two-dimensional array having pixel positions at respective intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and wherein the linear array of light-sensing elements of the image sensor is sequentially exposed to successive regularly spaced linear regions of the scene in multiple exposures, each one of the exposures producing a respective linear captured image brightness value array, the respective linear captured image brightness arrays produced by the multiple exposures being concatenated to form a two-dimensional captured image brightness value array having respective captured image brightness values at the pixel positions of the pixel position array.

4. The method of claim 1, wherein the image sensor has a two-dimensional array of light-sensing elements and the pixel position array is a two-dimensional array having the multiplicity of pixel positions at respective intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns.

1           5. The method of claim 4, wherein the off-grid positions of the off-grid position array are  
2 located at respective intersections of a plurality of regularly spaced intermediate rows and a  
3 plurality of regularly spaced intermediate columns, each one of the intermediate rows being  
4 parallel to the pixel rows and extending between a respective adjacent pair of the pixel rows,  
5 each one of the intermediate columns being parallel to the pixel columns and extending between  
6 a respective adjacent pair of the pixel columns.

01           6. The method of claim 4, wherein the off-grid positions of the off-grid position array are  
02 located at respective intersections of a plurality of regularly spaced intermediate rows and the  
03 pixel columns, and at respective intersections of a plurality of regularly spaced intermediate  
04 columns and the pixel rows, each one of the intermediate rows being parallel to the pixel rows  
05 and extending between a respective adjacent pair of the pixel rows, each one of the intermediate  
06 columns being parallel to the pixel columns and extending between a respective adjacent pair of  
07 the pixel columns.

1           7. The method of claim 3, wherein the off-grid positions of the off-grid position array are  
2 located at respective intersections of a plurality of regularly spaced intermediate columns and the  
3 pixel rows, each one of the intermediate columns being parallel to the pixel columns and  
4 extending between a respective adjacent pair of the pixel columns.

1           8. The method of claim 2, wherein the off-grid positions of the off-grid position array are  
2 located between respective adjacent pairs of pixel positions of the linear pixel position array.

1           9. The method of claim 1, wherein the step of deriving the output image from the  
2 estimated off-grid brightness values comprises using the estimated off-grid brightness values  
3 directly as the pixel brightness values of the output image.

1           10. The method of claim 1, wherein the step of deriving pixel brightness values of the  
2 output image from the estimated off-grid brightness values comprises resampling the estimated  
3 off-grid brightness values to derive respective resampled on-grid brightness values at the pixel  
4 positions of the pixel position array, the respective resampled on-grid brightness values at the  
5 pixel positions of the pixel position array being the pixel brightness values of the output image.

1           11. The method of claim 5, wherein the predetermined sensitivity pattern of the array of  
2 light-sensing elements has four different predetermined sensitivity levels and corresponds to a  
3 pixel position array having repetitive groups of four nearest neighbor pixel positions, each one of  
4 the four pixel positions in each group corresponding to a different one of the four predetermined  
5 sensitivity levels in a common predetermining positional order.

1           12. The method of claim 6, wherein the predetermined sensitivity pattern of the array of  
2 light-sensing elements has first and second predetermined sensitivity levels, and wherein  
3 adjacent pixel positions in each one of the pixel rows and adjacent pixel positions in each one of  
4 the pixel columns correspond to different ones of the first and second predetermined sensitivity  
5 levels.

1           13. The method of claim 7, wherein the predetermined sensitivity pattern of the array of  
2 light-sensing elements have first and second predetermined sensitivity levels, and adjacent pixel  
3 positions in each one of the pixel rows correspond to different ones of the predetermined first and  
4 second sensitivity levels, and adjacent pixel positions in each one of the pixel columns  
5 correspond to the same one of the predetermined first and second sensitivity levels.

1           14. The method of claim 1, wherein the step of estimating respective off-grid brightness  
2 values at the off-grid positions of the off-grid position array from respective captured image  
3 brightness values at the pixel positions of the pixel position array comprises the steps of: (1)  
4 estimating a sensitivity level off-grid brightness value for each different one of the sensitivity  
5 levels at each one of the off-grid positions using only captured image brightness values at pixel  
6 positions corresponding to the different one of the sensitivity levels; and (2) combining the  
7 sensitivity level off-grid brightness value estimated for each different one of the sensitivity levels

at each one of the off-grid positions to derive a respective estimated off-grid brightness values at each one of the off-grid positions.

15. The method of claim 14, wherein the step of combining the sensitivity level of brightness value for each different one of the sensitivity levels at each one of the off-grid positions comprises adding the sensitivity level off-grid brightness values estimated for each different one of the sensitivity levels at each one of the off-grid positions to derive the respective estimated off-grid brightness value at each one of the off-grid positions.

16. The method of claim 15, wherein the step of deriving pixel brightness values of the output image from the estimated off-grid brightness values comprises interpolating the estimated off-grid brightness values to derive respective interpolated on-grid brightness values at the pixel positions of the pixel position array, and compensating each one of the interpolated on-grid brightness values by the inverse of a combined response function of the light-sensing elements to obtain the pixel brightness values of the output image, the combined response function being the sum of weighted response functions of light-sensing elements having different ones of the sensitivity levels, each one of the weighted response functions being a response function of a light-sensing element having a respective one of the sensitivity levels multiplied by a predetermined weighting factor for the respective one of the sensitivity levels.

1           17. The method of claim 16, wherein the step of compensating each one of the  
2           interpolated on-grid brightness values by the inverse of the combined response function of the  
3           light-sensing elements comprises deriving from each one of the interpolated on-grid brightness  
4           values a respective index for a lookup table memory storing lookup table data representing the  
5           inverse of the combined response function of the light-sensing elements, retrieving from the  
6           lookup table memory a compensated interpolated on-grid brightness value corresponding to each  
7           index, and providing the compensated interpolated on-grid brightness values as the pixel  
8           brightness values of the output image.

1           18. The method of claim 14, wherein the step of combining the sensitivity level off-grid  
2           brightness value for each different one of the sensitivity levels at each one of the off-grid  
3           positions comprises the steps of: (1) multiplying the sensitivity level off-grid brightness value for  
4           each different one of the sensitivity levels at each one of the off-grid positions with a respective  
5           predetermined weighting factor corresponding to the different one of the sensitivity levels to  
6           derive a weighted sensitivity level off-grid brightness value for each different one of the  
7           sensitivity levels at each one of the off-grid positions; and (2) adding the weighted sensitivity  
8           off-grid level brightness value for each different one of the sensitivity levels at each one of the  
9           off-grid positions to derive the respective estimated off-grid brightness value at each one of the  
10          off-grid positions.

1           19. The method of claim 18, wherein the step of deriving the pixel brightness values of  
2 the output image from the estimated off-grid brightness values comprises interpolating the  
3 estimated off-grid brightness values to derive respective interpolated on-grid brightness values at  
4 the pixel positions of the pixel position array, and compensating each one of the interpolated on-  
5 grid brightness values by the inverse of a combined response function of the light-sensing  
6 elements to derive the pixel brightness values of the output image, the combined response  
7 function being the sum of weighted response functions of the light-sensing elements having  
8 different ones of the sensitivity levels, each one of the weighted response functions being a  
9 response function of a light-sensing element having a respective one of the sensitivity levels  
10 multiplied by a predetermined weighting factor for the respective one of the sensitivity levels.

11           20. The method of claim 19 wherein the step of compensating each one of the  
12 interpolated brightness values by the inverse of a combined response function of the light-  
13 sensing elements comprises using each one of the interpolated on-grid brightness values to derive  
14 a respective index for a lookup table memory storing data representing the inverse of the  
15 combined response function of the light-sensing elements, retrieving from the lookup table  
16 memory a respective compensated interpolated on-grid brightness value corresponding to each  
17 index, and providing the compensated interpolated on-grid brightness values as the pixel  
18 brightness values of the output image.



1           21. The method of claim 1, wherein the step of estimating respective off-grid brightness  
2 values at the off-grid positions of the off-grid position array from respective captured image  
3 brightness values at the pixel positions of the pixel position array comprises the steps of: (1)  
4 estimating a sensitivity level off-grid brightness value for each different one of the sensitivity  
5 levels at each one of the off-grid positions using only the captured image brightness values at  
6 pixel positions corresponding to the different one of the sensitivity levels; (2) combining the  
7 sensitivity level off-grid brightness value estimated for each different one of the sensitivity levels  
8 at each one of the off-grid positions to derive a combined sensitivity level off-grid brightness  
9 value at each one of the off-grid positions; and (3) compensating the combined sensitivity level  
10 off-grid brightness value at each one of the off-grid positions by the inverse of a combined  
11 response function of the light-sensing elements to derive a respective estimated off-grid  
12 brightness value at each one of the off-grid positions, the combined response function being the  
13 sum of weighted response functions of light-sensing elements having different ones of the  
14 sensitivity levels, each one of the weighted response functions being a response function of a  
15 light-sensing element having a respective one of the sensitivity levels multiplied by a  
16 predetermined weighting factor for the respective one of the sensitivity levels.

1           22. The method of claim 21, wherein the step of compensating the combined sensitivity  
2 level off-grid brightness value at each one of the off-grid positions by the inverse of the  
3 combined response function of the light-sensing elements comprises using the combined

4 sensitivity level off-grid brightness value at each one of the off-grid positions to derive a  
5 respective index for a lookup table memory storing data representing the inverse of the combined  
6 response function of the light-sensing elements, retrieving from the lookup table a compensated  
7 combined sensitivity level off-grid brightness value corresponding to each index, and providing  
8 the compensated combined sensitivity level off-grid brightness values retrieved from the lookup  
9 table as the respective estimated off-grid brightness values at the off-grid positions.

1 23. The method of claim 21, wherein the step of combining the sensitivity level off-grid  
2 brightness value estimated for each different one of the sensitivity levels at each one of the off-  
3 grid positions comprises adding the sensitivity level off-grid brightness value for each different  
4 one of the sensitivity levels at each one of the off-grid positions to derive the respective  
5 combined sensitivity level off-grid brightness values at the off-grid positions.

1 24. The method of claim 21, wherein the step of combining the sensitivity level off-grid  
2 brightness value estimated for each different one of the sensitivity levels at each one of the off-  
3 grid positions comprises the steps of: (1) multiplying the sensitivity level off-grid brightness  
4 value estimated for each different one of the sensitivity levels at each one of the off-grid  
5 positions by a respective predetermined weighting factor corresponding to the different one of  
6 the sensitivity levels to derive a weighted sensitivity level off-grid brightness value for each  
7 different one of the sensitivity levels at each one of the off-grid positions; and (2) summing the

8 weighted sensitivity off-grid level brightness value for each different one of the sensitivity levels  
9 at each one of the off-grid positions to derive the combined sensitivity level off-grid brightness  
10 value at each one of the off-grid positions.

1 25. The method of claim 14 or 21, wherein the step of estimating the sensitivity level off-  
2 grid brightness value for each different one of the sensitivity levels at each one of the off-grid  
3 positions comprises the steps of: (1) masking the pixel positions but leaving unmasked pixel  
4 positions corresponding to the different one of the sensitivity levels; and (2) estimating the  
5 sensitivity level off-grid brightness value for the different one of the sensitivity levels at the one  
6 of the off-grid positions to be equal to the captured image brightness value at the one of the  
7 unmasked pixel positions nearest the one of the off-grid positions.

1 26. The method of claim 24, wherein the array of light-sensing elements of the image  
2 sensor is a linear array and the pixel position array is a linear array having pixel positions at  
3 respective regularly spaced pixel positions in a pixel row and the off-grid positions of the off-  
4 grid position array are each located between respective pairs of adjacent pixel positions of the  
5 linear pixel position array, and wherein the step of estimating a sensitivity level off-grid  
6 brightness value for each different one of the sensitivity levels at each one of the off-grid  
7 positions comprises providing as the sensitivity level off-grid brightness value for each different  
8 one of the sensitivity levels at each one of the off-grid positions the captured image brightness

values at pixel positions corresponding to the different one of the sensitivity levels that is the nearest neighbor to the one of the off-grid positions.

27. The method of claim 26, wherein the predetermined sensitivity pattern of the light-sensing elements has first and second predetermined sensitivity levels, and adjacent pixel positions of the linear pixel position array correspond to different ones of the first and second predetermined sensitivity levels, and wherein the step of multiplying the sensitivity level off-grid brightness value for each different one of the sensitivity levels at each one of the off-grid positions by a respective predetermined weighting factor corresponding to the different one of the sensitivity levels to derive a weighted sensitivity level off-grid brightness value for each different one of the sensitivity levels at each one of the off-grid positions, and the step of summing the weighted sensitivity level off-grid brightness value for each different one of the sensitivity levels at each one of the off-grid positions to derive the combined sensitivity level off-grid brightness value at each one of the off-grid positions is expressed as

$$B(x') = W_1 I_c(x' - 0.5) + W_2 I_c(x' + 0.5),$$

where  $B(x')$  is the combined sensitivity level off-grid brightness value at off-grid position  $x'$ ,  $W_1$  is the predetermined weighting factor for the sensitivity level corresponding to pixel position  $(x' - 0.5)$ ,  $W_2$  is the weighting factor for the sensitivity level corresponding to pixel position  $(x' + 0.5)$ ,  $I_c(x' - 0.5)$  is the captured image brightness value at pixel position  $(x' - 0.5)$  and

17  $I_c(x' + 0.5)$  is the captured image brightness value at pixel position  $(x' + 0.5)$ , and wherein the  
 18 combined response function of the light-sensing elements is expressed as

$$S(E) = W_1 P_1(E) + W_2 P_2(E),$$

20 where  $P_1(E)$  is the radiometric response function of a light-sensing element having the sensitivity  
 21 level corresponding to pixel position  $(x' - 0.5)$  and  $P_2(E)$  is the radiometric response function of  
 22 a light-sensing element having the sensitivity level corresponding to pixel position  $(x' + 0.5)$ .

28. The method of claim 1, wherein the step of estimating respective off-grid brightness  
 values at the off-grid positions of the off-grid position array from respective captured image  
 brightness values at the pixel positions of the pixel position array comprises bi-linear sampling  
 with interpolation of the captured image brightness values at the pixel positions.

29. The method of claim 1, wherein the step of estimating respective off-grid brightness  
 values at the off-grid positions of the off-grid position array from respective captured image  
 brightness values at the pixel positions of the pixel position array comprises bi-cubic sampling  
 with interpolation of the captured image brightness values at the pixel positions.

30. The method of claim 1, wherein the step of estimating respective off-grid brightness  
 values at the off-grid positions of the off-grid position array from respective captured image  
 brightness values at the pixel positions of the pixel position array comprises estimating a a

4     respective off-grid brightness value at each individual one of the off-grid positions by comparing  
5     a respective captured image brightness value at each one of a predetermined number of pixel  
6     positions that are nearest neighbors to the individual one of the off-grid positions with a  
7     predetermined low threshold value and a predetermined high threshold value, computing the sum  
8     of the nearest neighbor pixel position captured image brightness values that are greater than the  
9     predetermined low threshold value and less than the predetermined high threshold value, and  
10    dividing the sum by the number of nearest neighbor pixel position brightness values included in  
11    the sum.

1             31. The method of claim 1, wherein the step of estimating off-grid brightness values at  
2     the off-grid positions of the off-grid position array from respective captured image brightness  
3     values at the pixel positions of the pixel position array comprises estimating a respective off-grid  
4     brightness value at each individual one of the off-grid positions by comparing a respective  
5     compensated captured image brightness value at each one of a predetermined number of pixel  
6     positions that are nearest neighbors to the individual one of the off-grid positions with a  
7     predetermined low threshold value a predetermined high threshold value, computing the sum of  
8     the compensated captured image brightness values at the nearest neighbor pixel positions that are  
9     greater than the predetermined low threshold value and less than the predetermined high  
10    threshold value, and deriving a respective estimated off-grid brightness value at the individual  
11    one of the off-grid positions by dividing the sum by the number of compensated captured image

12 brightness values at nearest neighbor pixel positions, the respective compensated captured image  
13 brightness value at each one of the nearest neighbor pixel positions being the captured image  
14 brightness value at the one of the nearest neighbor pixel positions compensated by the inverse of  
15 the response function of a light-sensing element having a sensitivity level corresponding to the  
16 one of the nearest neighbor pixel positions.

1 32. The method of claim 31, wherein the respective compensated captured image  
2 brightness value at each one of the nearest neighbor pixel positions is derived by using the  
3 captured image brightness value at the one of the nearest neighbor pixel positions to derive an  
4 index for a lookup table memory storing data representing the inverse response functions of  
5 light-sensing elements having different ones of the plurality of sensitivity levels, and retrieving  
6 from the lookup table memory a compensated captured image brightness value corresponding to  
7 the index from lookup table data representing the inverse of the response function of a light-  
8 sensing element having the sensitivity level of the one of the nearest neighbor pixel positions.

1 33. The method of claim 5, wherein each one of the intermediate rows extends medially  
2 between a respective adjacent pair of the pixel rows and each one of the intermediate columns  
3 extends medially between a respective adjacent pair of the pixel columns, and wherein the step of  
4 estimating respective off-grid brightness values at the off-grid positions of the off-grid position  
5 array from respective captured image brightness values at the pixel positions of the pixel position

array comprises estimating the brightness value at each one of the off-grid positions  $(x', y')$ , where  $x'$  has values from 1 to  $xSize-1$ ,  $y'$  has values from 1 to  $ySize-1$ , and  $xSize$  and  $ySize$  are the dimensions of the captured image in the direction of the pixel rows and the pixel columns, respectively, the step of estimating respective off-grid brightness values at each one of the off-grid positions  $(x', y')$  comprising:

(i) comparing a respective brightness value  $I(u, v)$  at each one of sixteen pixel positions  $(u, v)$  that are nearest neighbors to the one of the off-grid positions  $(x', y')$  with a predetermined low threshold value and a predetermined high threshold value, where  $u$  has values from  $x' - 5$  to  $x' + 0.5$  and  $v$  has values from  $y' - 0.5$  to  $y' + 0.5$ ;

(ii) for each one of the brightness values  $I(u, v)$  at the sixteen nearest neighbor pixel positions  $(u, v)$  that is greater than the predetermined low threshold value and less than the predetermined high threshold value, computing indices  $i$  and  $j$  of a  $4 \times 4$  cubic interpolation kernel  $\phi$  using the relations  $i = x' - u - 1.5$  and  $j = y' - v - 1.5$ , and computing the quantities

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2}$$

and  $\phi_{ij}^2$ , where  $\phi_{mn}$  is the value of the  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices  $m$  and  $n$ ;

(iii) adding the quantities

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2}$$



21 computed in step (ii) to derive a first sum s;

22 (iv) adding the quantities  $\phi_{ij}^2$  computed in step (ii) to derive a second sum w; and

23 (v) computing the estimated brightness value at the one of the off-grid positions

24 (x',y') by dividing the first sum s by the second sum w.

1 34. The method of claim 33, wherein the brightness value I(u,v) at nearest neighbor pixel  
2 position (u,v) compared with the predetermined low threshold and the predetermined high  
3 threshold value in step (i) is the captured image brightness value at pixel position (u,v).

1 35. The method of claim 33, wherein the brightness value I(u,v) at nearest neighbor pixel  
2 position (u,v) compared with the predetermined low threshold value and the predetermined high  
3 threshold value in step (i) is the captured image brightness value at pixel position (u,v)  
4 compensated by the inverse of a response function of a light-sensing element having the  
5 sensitivity level corresponding to pixel position (u,v).

1 36. The method of claim 35, wherein the captured image brightness value at each one of  
2 the nearest neighbor pixel positions (u,v) is compensated by the inverse of the response function  
3 of a light-sensing element having the sensitivity level corresponding to one of the nearest  
4 neighbor pixel positions (u,v) by using the captured image brightness value to derive an index for  
5 a lookup table memory storing data representing the inverse of response functions of light-

6 sensing elements having different ones of the plurality of sensitivity levels, and retrieving from  
7 the lookup table memory a compensated captured image brightness value corresponding to the  
8 index using lookup table data representing the inverse of the response function of a light-sensing  
9 element having the sensitivity level corresponding to the one of the nearest neighbor pixel  
10 positions (u,v), the retrieved compensated brightness value being the brightness value  $I(u,v)$  at  
11 the one of the nearest neighbor pixel positions (u,v).

1 37. The method of claim 2, wherein the step of estimating respective off-grid brightness  
2 values at the off-grid positions of the off-grid position array from the respective captured image  
3 brightness values at the pixel positions of the pixel position array comprises estimating the  
4 brightness value at each one of the off-grid positions  $x'$ , where  $x'$  has values from 2 to  $xSize - 2$ ,  
5  $xSize$  being the dimension of the captured line image, the step of estimating the off-grid  
6 brightness value at each one of the off-grid positions  $x'$  comprising:

7 (i) comparing a respective brightness value  $I(k)$  at each one of four pixel positions  
8  $k$  that are nearest neighbors to the one of the off-grid positions  $x'$  with a predetermined low  
9 threshold value and a predetermined high threshold value, where  $k$  has values from  $x' - 1.5$  to  
10  $x' + 1.5$ ;

11 (ii) for each one of the brightness values  $I(k)$  at the four nearest neighbor pixel  
12 positions  $k$  that is greater than the predetermined low threshold value and less than the

predetermined high threshold value computing the quantity  $I(k) G(k-x')$ , where  $G(k-x')$  is the value of a  $4 \times 1$  Gaussian interpolation kernel  $G$  at position  $(k-x')$ ;

(iii) adding the quantities  $I(k) G(k-x')$  computed in step (ii) to derive a first sum  $p$ ;

(iv) adding the quantities  $G(k-x')$  used in the computations of step (ii) to derive a second sum  $q$ ; and

(v) computing the estimated brightness value at the one of the off-grid position  $x'$  by dividing the first sum  $p$  by the second sum  $q$ .

38. The method of claim 37, wherein the respective brightness value  $I(k)$  at nearest neighbor pixel position  $k$  compared with the predetermined low threshold value and the predetermined high threshold value in step (i) is the captured image brightness value at nearest neighbor pixel position  $k$ .

39. The method of claim 37, wherein the brightness value  $I(k)$  at nearest neighbor pixel position  $k$  compared with the predetermined low threshold value and the predetermined high threshold value in step (i) is the captured image brightness value at nearest neighbor pixel position  $k$  compensated by the inverse of a light-sensing element having the sensitivity level corresponding to pixel position  $k$ .

1           40. The method of claim 39, wherein the captured image brightness value at each one of  
2 the nearest neighbor pixel positions  $k$  is compensated by the inverse of the response function of a  
3 light-sensing element having the sensitivity level corresponding to the one of the nearest  
4 neighbor pixel positions  $k$  by using the captured image brightness value at the one of the nearest  
5 neighbor pixel positions  $k$  to an index for a lookup table memory storing data representing the  
6 inverse of response functions of light-sensing elements having different ones of the plurality of  
7 sensitivity levels, and retrieving from the lookup table memory a compensated captured image  
8 brightness value corresponding to the index using lookup table data representing the inverse of  
9 the response function of a light-sensing element having the sensitivity level corresponding to the  
10 one of the nearest neighbor pixel positions  $k$ , the retrieved compensated captured image  
11 brightness value being the brightness value  $I(k)$  at the one of the nearest neighbor pixel  
12 position  $k$ .

1           41. The method of claim 37, wherein the  $4 \times 1$  Gaussian kernel  $G$  has the form:

|     |     |     |     |
|-----|-----|-----|-----|
| 1.0 | 7.7 | 7.7 | 1.0 |
|-----|-----|-----|-----|

1           42. The method of claim 10, wherein the step of resampling the estimated off-grid  
2 brightness values to derive respective resampled on-grid brightness values at the pixel positions

of the pixel position array comprises deriving the resampled brightness value at each individual one of the pixel positions by computing the product of respective off-grid brightness values at a predetermined number of off-grid positions that are nearest neighbors to the individual one of the pixel positions and cubic interpolation kernel having the same dimensions as the predetermined number of off-grid positions.

43. The method of claim 5, wherein the step of deriving pixel brightness values of an output image from the estimated off-grid brightness values comprises resampling the estimated off-grid brightness values to derive resampled on-grid brightness values at the pixel positions of the pixel position array, and wherein each one of the intermediate rows extends medially between a respective adjacent pair of pixel rows and each one of the intermediate columns extends medially between a respective adjacent pair of pixel columns, and wherein the resampled brightness value at each one of the multiplicity of pixel positions is computed by the relation:

$$I(x-2, y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x-1.5 + i, y-1.5 + j) \phi_{ij},$$


where x has values from 2.5 to xSize-2.5, y has values from 2.5 to ySize-2.5, I(x-2, y-2) is the resampled on-grid brightness value at pixel position (x-2, y-2), B(x-1.5+i, y-1.5+j) is the estimated off-grid brightness value at off-grid position (x-1.5+i, y-1.5+j), i and j are indices of a 4 × 4 cubic interpolation kernel  $\phi$ ; the indices i and j each have values from 0 to 3,  $\phi_{ij}$  is the

value of the interpolation kernel  $\phi$  at indices  $i$  and  $j$ ,  $xSize$  is the dimension of the captured image in the direction of the pixel rows, and  $ySize$  is the dimension of the captured image in the direction of the pixel columns.

44. The method of claim 33 or 43, wherein the  $4 \times 4$  cubic interpolation kernel  $\phi$  has the form:

|        |        |        |        |
|--------|--------|--------|--------|
| 0.043  | -0.66  | -0.661 | 0.043  |
| -0.661 | 10.28  | 10.28  | -0.661 |
| -0.661 | 10.28  | 10.28  | -0.661 |
| 0.043  | -0.661 | -0.661 | 0.043  |

•



45. The method of claim 2, wherein the step of deriving pixel brightness values of an output image from the estimated off-grid brightness values comprises resampling the estimated off-grid brightness values to derive resampled on-grid brightness values at pixel positions of the pixel position array, and wherein each off-grid position is located midway between a respective adjacent pair of pixel positions, and the resampled on-grid brightness values  $I_o$  at each one of the pixel positions  $x$  is computed by the relation:

$$I_o(x-3) = \sum_{k=-1.5}^{k=1.5} B(x+k)\psi(k),$$

where  $x$  is the coordinate of the pixel position having values from 3.5 to  $xSize-3.5$ ,  $I_o(x-3)$  is the resampled on-grid brightness value at pixel position  $(x-3)$ ,  $B(x+k)$  is the estimated off-grid

brightness value at off-grid position  $(x+k)$ ,  $k$  is a position of a  $4 \times 1$  cubic interpolation kernel  $\psi$ ,  $\psi(k)$  is the value of the cubic interpolation kernel  $\psi$  at position  $k$ , the position  $k$  has values from  $-1.5$  to  $1.5$ , and  $xSize$  is the dimension of the captured line image.

46. The method of claim 45, wherein the  $4 \times 1$  cubic interpolation kernel  $\psi$  has the form:

|       |       |       |       |
|-------|-------|-------|-------|
| -0.96 | 13.44 | 13.44 | -0.96 |
|-------|-------|-------|-------|

$k$

47. The method of claim 6, wherein each one of the intermediate rows extends medially between a respective adjacent pair of the pixel rows and each one of the intermediate columns extends medially between a respective adjacent pair of the pixel columns, and the step of estimating respective off-grid brightness values at the off-grid positions of the off-grid position array from respective captured image brightness values at the pixel positions of the pixel position array comprises estimating the off-grid brightness value at each one of the off-grid positions  $(x', y')$ , where  $x'$  has values from  $0.5$  to  $xSize-0.5$  and  $y'$  has values from  $1$  to  $ySize-1$  for off-grid positions located at respective intersections of the intermediate rows and the pixel columns,  $x'$  has values from  $1$  to  $xSize-1$  and  $y'$  has values from  $0.5$  to  $ySize-0.5$  for off-grid positions located at respective intersections of the pixel rows and the intermediate columns, and  $xSize$  and  $ySize$  are the dimensions of the captured image in the directions of the pixel rows and the pixel

columns, respectively, the step of estimating the brightness values at each one of the off-grid positions  $(x', y')$  comprising:

(i) for each one of the off-grid positions  $(x', y')$  computing coordinates  $(u, v)$  using the relations  $u = x' + 0.5i - 0.5j$  and  $v = y' - 1.5 + 0.5i + 0.5j$ , where  $i$  and  $j$  are indices of a  $4 \times 4$  cubic interpolation kernel  $\phi$ , and each one of the indices  $i$  and  $j$  has values from 0 to 3;

(ii) for each pair of coordinates  $(u, v)$  computed in step (i) using indices  $i$  and  $j$ , determining whether the coordinates  $(u, v)$  are those of a pixel position;

(iii) if the coordinates  $(u, v)$  computed in step (i) are the coordinates of a pixel position, comparing a brightness value  $I(u, v)$  at the pixel position  $(u, v)$  with a predetermined low-threshold value and a predetermined high threshold value;

(iv) if the coordinates  $(u, v)$  computed in step (i) using indices  $i$  and  $j$  are those of a pixel position and the brightness value  $I(u, v)$  is greater than the predetermined low threshold value and less than the predetermined high threshold value, then compute the quantities:

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2}$$

and  $\phi_{ij}^2$ , where  $\phi_{m,n}$  is the value of a  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices  $m$  and  $n$ ;

(v) adding the quantities

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2}$$



computed in step (iv) to derive a first sum  $s$ ;

(vi) adding the quantities  $\phi_{ij}^2$  computed in step (iv) to derive a second sum  $w$ ; and

(vii) computing the estimated brightness value at the one of the off-grid positions  $(x', y')$  by dividing the first sum  $s$  by the second sum  $w$ .

48. The method of claim 47, wherein the brightness value  $I(u,v)$  at each one of the pixel positions  $(u,v)$  compared with the predetermined low threshold value and the predetermined high threshold value in step (iii) is the captured image brightness value at the one of the pixel positions  $(u,v)$ .

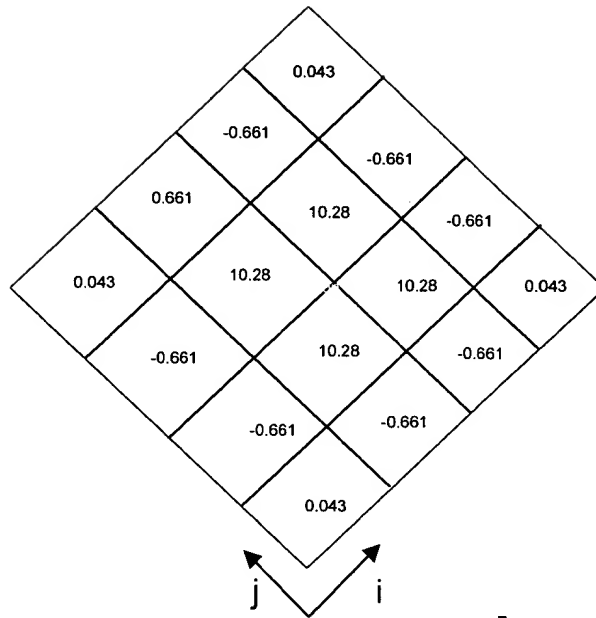
49. The method of claim 47, wherein the brightness value  $I(u,v)$  at each one of the pixel positions  $(u,v)$  compared with the predetermined low threshold value and the predetermined high threshold value in step (iii) is the captured image brightness value at the one of the pixel positions  $(u,v)$  compensated by the inverse of the response function of a light-sensing element having a sensitivity level corresponding to the one of the pixel positions  $(u,v)$ .

50. The method of claim 49, wherein the captured image brightness value at each one of the pixel positions  $(u,v)$  is compensated by the inverse of the response function of a light-sensing element having the sensitivity level corresponding to the one of the pixel positions  $(u,v)$  by using the captured image brightness value  $I_c(u,v)$  at the one of the pixel positions  $(u,v)$  to derive an

5 index for a lookup table memory storing data representing the inverse of response functions of  
 6 light-sensing elements having different ones of the plurality of sensitivity levels, and retrieving  
 7 from the lookup table a compensated captured image brightness value corresponding to the index  
 8 using lookup table data representing the inverse of the response function of a light-sensing  
 9 element having the sensitivity level corresponding to the one of the pixel positions (u,v), the  
 10 retrieved compensated captured image brightness value being the brightness value  $I(u,v)$  at the  
 11 one of the pixel positions (u,v).

51. The method of claim 47, wherein the step of estimating the off-grid brightness value  
 at each one of the off-grid positions (x', y') is first carried out for off-grid positions located at  
 respective intersections of intermediate rows and pixel columns, and then carried out for pixel  
 positions located at respective intersections of pixel rows and intermediate columns.

52. The system of claim 47, wherein the 4 X 4 cubic interpolation kernel  $\phi$  has the form:



53. The method of claim 6, wherein the step of deriving pixel brightness values of an output image from the estimated off-grid brightness values comprises resampling the estimated off-grid brightness values to derive respective resampled on-grid brightness values at pixel positions of the pixel position array, and each one of the intermediate rows extends medially between a respective adjacent pair of the pixel rows and each one of the intermediate columns extends medially between a respective adjacent pair of the pixel columns, and wherein the resampled on-grid brightness value at each one of the pixel positions (x,y) is computed by the relation:

$$I(x-2, y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x+0.5i-0.5j, y-1.5+0.5i+0.5j) \phi_{ij}$$

where x has values from 2.5 to xSize - 2.5, y has values from 2.5 to ySize - 2.5, I(x-2, y-2) is the resampled on-grid brightness value at pixel position (x-2, y-2), B(x+0.5i-0.5j, y-1.5+0.5i+0.5j) is the off-grid brightness value at off-grid position (x+0.5i-j0.5j, y-1.5+0.5i+0.5j), i and j are indices of a 4 × 4 cubic interpolation kernel  $\phi$ , indices i and j each have values from 0 to 3,  $\phi_{ij}$  is the value of the interpolation kernel  $\phi$  at indices i and j, xSize is the dimension of the captured image in the direction of the pixel rows, and ySize is the dimension of the captured image in the direction of the pixel columns.

54. The method of claim 5, wherein the step of deriving pixel brightness values of an output image from the estimated off-grid brightness values comprises using a Gaussian kernel for interpolating the estimated off-grid brightness values to derive respective interpolated brightness values at the pixel positions of the pixel position array.

55. The method of claim 54, wherein the Gaussian kernel has the form:

|        |        |        |        |        |        |
|--------|--------|--------|--------|--------|--------|
| 0.0037 | 0.0101 | 0.0166 | 0.0166 | 0.0101 | 0.0037 |
| 0.0101 | 0.0275 | 0.0452 | 0.0452 | 0.0275 | 0.0101 |
| 0.0166 | 0.0452 | 0.0743 | 0.0743 | 0.0452 | 0.0166 |
| 0.0166 | 0.0452 | 0.0743 | 0.0743 | 0.0452 | 0.0166 |
| 0.0101 | 0.0275 | 0.0452 | 0.0452 | 0.0275 | 0.0101 |
| 0.0037 | 0.0101 | 0.0166 | 0.0166 | 0.0101 | 0.0037 |

56. The method of claim 5, wherein the step of deriving pixel brightness values of an output image from the estimated off-grid brightness values comprises using a bi-linear interpolation filter kernel for interpolation of the off-grid brightness values to derive respective interpolated on-grid brightness values at the pixel positions of the pixel position array.

57. The method of claim 56, wherein the bi-linear interpolation filter kernel has the form:

|     |     |
|-----|-----|
| 0.5 | 0.5 |
| 0.5 | 0.5 |

58. The method of claim 5 or 7, wherein the step of deriving pixel brightness value of an output image from the estimated off-grid brightness values comprises resampling the estimated off-grid brightness values to derive respective resampled on-grid brightness values at

4 the pixel positions of the pixel position array, and wherein the step of resampling the estimated  
5 off-grid brightness values comprises shifting the off-grid position array to coincide with the pixel  
6 position array, whereby the resampled on-grid brightness values at the pixel positions of the pixel  
7 position array are the respective estimated off-grid brightness values at the coincident off-grid  
8 positions of the shifted off-grid position array.

1 59. A method for obtaining a relatively high dynamic range image of a scene using a  
2 relatively low dynamic range image sensor exposed to incident light from the scene for capturing  
3 an image thereof, the image sensor having a multiplicity of light-sensing elements in an array,  
4 each light-sensing element having a particular one of a plurality of sensitivity levels to incident  
5 light in accordance with a predetermined sensitivity pattern for the array of light-sensing  
6 elements and having a respective response function, each light-sensing element being responsive  
7 to incident light from the scene for producing a captured image brightness value at a  
8 corresponding one of a multiplicity of pixel positions of a pixel position array, whereby each one  
9 of the multiplicity of pixel positions corresponds to a particular one of the plurality of sensitivity  
10 levels of the light-sensing elements, the method comprising the steps of computing respective  
11 on-grid brightness values at pixel positions of the pixel position array from respective captured  
12 image brightness values at the pixel positions of the pixel position array, each one of the  
13 respective on-grid brightness values being computed from a corresponding plurality of the

14 captured image brightness values, and deriving pixel brightness values of an output image from  
15 the on-grid brightness values.

1 60. The method of claim 59, wherein the array of light-sensing elements of the image  
2 sensor is a linear array for capturing a line image, and the pixel position array is a linear array  
3 having the multiplicity of pixel positions at respective regularly spaced pixel positions in a pixel  
4 row so as to form a linear captured image brightness value array.

5 61. The method of claim 59, wherein the array of light-sensing elements of the image  
6 sensor is a linear array and the pixel position array is a two-dimensional array having pixel  
7 positions at respective intersections of a plurality of regularly spaced pixel rows and a plurality  
8 of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and  
9 wherein the linear array of light-sensing elements of the image sensor is sequentially exposed to  
10 successive regularly spaced linear regions of the scene in multiple exposures, each one of the  
exposures producing a respective linear captured image brightness value array, the respective  
linear captured image brightness value arrays produced by the multiple exposures being  
concatenated to form a two-dimensional captured image brightness value array having respective  
captured image brightness values at the pixel positions of the pixel position array.

1           62. The method of claim 59, wherein the image sensor has a two-dimensional array of  
2 light-sensing elements, and the pixel position array is a two-dimensional array having the  
3 multiplicity of pixel positions at respective intersections of a plurality of regularly spaced pixel  
4 rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the  
5 pixel columns.

1           63. The method of claim 59, wherein the step of deriving pixel brightness values of an  
2 output image from the on-grid brightness values comprises using the respective on-grid  
3 brightness values at the pixel positions of the pixel position array as the pixel brightness values  
4 of the output image.

1           64. The method of claim 59, wherein the step of deriving pixel brightness values of an  
2 output image from the on-grid brightness values comprises compensating the respective on-grid  
3 brightness value at each one of the pixel positions of the pixel position array by the inverse of a  
4 combined response function of the light-sensing elements to obtain respective pixel brightness  
5 values of the output image at the pixel positions of the pixel position array, the combined  
6 response function being the sum of weighted response functions of the light-sensing elements  
7 having different ones of the plurality of sensitivity levels, each one of the weighted response  
8 functions being the response function of a light-sensing element having a respective one of the



9 sensitivity levels multiplied by a predetermined weighting factor for the respective one of the  
10 sensitivity levels.

1 65. The method of claim 64, wherein the step of compensating the on-grid brightness  
2 value at each one of the pixel positions of the pixel position array comprises the steps of deriving  
3 from the on-grid brightness value at each one of the pixel positions a respective index for a  
4 lookup table memory storing data representing the inverse of the combined response function of  
5 the light-sensing elements, and retrieving from the lookup table memory a compensated on-grid  
6 brightness value corresponding to the respective index, the compensated on-grid brightness value  
7 being the pixel brightness value of the output image at the one of the pixel positions.

1 66. The method of claim 59, wherein the step of computing respective on-grid brightness  
2 values at pixel positions of the pixel position array comprises computing the respective on-grid  
3 brightness value at each one of the pixel positions by calculating the product of the captured  
4 image brightness values at a predetermined number of pixel positions that are nearest neighbors  
5 to the one of the pixel positions and an on-grid interpolation filter kernel having the same  
6 dimensions as the predetermined number of pixel positions.

1 67. The method of claim 66, wherein the image sensor has a two-dimensional array of  
2 light-sensing elements, and the pixel array is a two-dimensional array having the multiplicity of

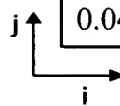
3 pixel positions at respective intersections of a plurality of regularly spaced pixel rows and a  
 4 plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel  
 5 columns, and wherein the on-grid brightness value at each one of the pixel positions (x,y) of the  
 6 pixel position array is calculated by the relation

$$I(x-2,y-2) = \sum_{i=0}^4 \sum_{j=0}^4 I_c(x-2 + i, y-2 + j)\phi_{ij},$$

7 where x has values from 2.5 to xSize - 2.5, y has values from 2.5 to ySize - 2.5, I(x - 2, y - 2) is  
 8 the interpolated brightness value at pixel position (x - 2, y - 2),  $I_c(x - 2 + i, y - 2 + j)$  is the  
 9 captured image brightness value at pixel position (x - 2 + i, y - 2 + j), i and j are indices of a 5 x 5  
 10 on-grid interpolation filter kernel  $\phi$ , the indices i and j each have values from 0 to 4,  $\phi_{ij}$  is the  
 11 value of the on-grid interpolation filter kernel  $\phi$  at indices i and j, xSize is the dimension of the  
 12 captured image in the direction of the pixel rows, and ySize is the dimension of the captured  
 13 image in the direction of the pixel columns.

68. The method of claim 67, wherein the  $5 \times 5$  on-grid interpolation filter kernel  $\phi$  has the form:

|        |        |        |        |        |
|--------|--------|--------|--------|--------|
| 0.043  | -0.618 | -1.322 | 0.618  | 0.043  |
| -0.618 | 9.001  | 19.238 | 9.001  | -0.618 |
| -1.322 | 19.238 | 41.12  | 19.238 | -1.322 |
| -0.618 | 9.001  | 19.238 | 9.001  | -0.618 |
| 0.043  | -0.618 | -1.322 | -0.618 | 0.043  |



69. The method of claim 59, wherein the step of computing respective on-grid brightness values at pixel positions of the pixel position array comprises computing a respective on-grid brightness value at each individual one of the pixel positions of the pixel position array including the steps of :

(i) comparing a respective compensated captured image brightness value at each one of a predetermined number of pixel positions that are nearest neighbors to the individual one of the pixel positions with a predetermined low threshold value and a predetermined high threshold value;

(ii) for each one of the nearest neighbor pixel positions having a compensated captured image brightness value greater than the predetermined low threshold value and less than the predetermined high threshold value, computing the product of the compensated captured image

12 brightness value at the one of the nearest neighbor pixel positions and the value of an on-grid  
13 interpolation filter kernel corresponding to the one of the nearest neighbor pixel positions, the  
14 on-grid interpolation filter kernel having the same dimensions as the predetermined number of  
15 nearest neighbor pixel positions;

16 (iii) computing a first sum of all products computed in step (ii);

17 (iv) computing a second sum of all values of the on-grid interpolation filter kernel used  
18 to compute a product in step (ii); and

19 (v) computing the on-grid brightness value at the individual one of the pixel positions by  
20 dividing the first sum by the second sum, wherein the respective compensated captured image  
21 brightness value at each one of the nearest neighbor pixel positions is the respective captured  
22 image brightness value at the one of the nearest neighbor pixel positions compensated by the  
23 inverse of the response function of a light-sensing element having the sensitivity level  
24 corresponding to the one of the nearest neighbor pixel positions.

1 70. The method of claim 69, further comprising the steps of using the captured image  
2 brightness value at each one of the pixel positions of the pixel position array to derive a  
3 respective index for a lookup table storing data representing the inverse of response functions of  
4 light-sensing elements having different ones of the plurality of sensitivity levels, and retrieving  
5 from the lookup table a compensated captured image brightness value corresponding to the  
6 respective index from lookup table data representing the inverse of the response function of the

7 light-sensing element having the sensitivity level corresponding to the one of the pixel positions,  
8 the retrieved compensated captured image brightness value being the compensated captured  
9 image brightness value at the one of the pixel positions.

1 71. A method for obtaining a relatively high dynamic range image of a scene using a  
2 relatively low dynamic range image sensor exposed to incident light from the scene for capturing  
3 an image thereof, the image sensor having a multiplicity of light-sensing elements in a linear  
4 array, each light-sensing element having a particular one of a plurality of sensitivity levels to  
5 incident light in accordance with a predetermined sensitivity pattern for the array of light-sensing  
6 elements and having a respective response function, each light-sensing element being responsive  
7 to incident light from the scene for producing a captured image brightness value at a  
8 corresponding one of a multiplicity of pixel position at respective regularly spaced pixel  
9 positions of a linear pixel position array to form a linear captured image brightness value array,  
10 whereby each one of the multiplicity of pixel positions corresponds to a particular one of the  
11 plurality of sensitivity levels, the method comprising the steps of:

12 (i) for each one of the pixel positions  $x$  of the pixel position array, where  $x$  has  
13 values from  $2.5$  to  $xSize-2.5$  and  $xSize$  is the dimension of the captured image, comparing each  
14 one of brightness values  $I(k)$  at five pixel positions  $k$  that are nearest neighbors to pixel position  
15  $x$  with a predetermined low threshold value and a predetermined high threshold value, where  $k$   
16 has values from  $x-2$  to  $x+2$ ;

(ii) for each one of the brightness values  $I(k)$  at the five nearest neighbor pixel positions  $k$  that is greater than the predetermined low threshold value and less than the predetermined high threshold value, computing the quantity  $I(k)G(k-x)$ , where  $G(k-x)$  is the value of a Gaussian interpolation kernel  $G$  at position  $(k-x)$ ;

(iii) adding the quantities  $I(k)G(k-x)$  computed in step (ii) to derive a first sum  $p$ ;

(iv) adding the Gaussian interpolation kernel values  $G(k-x)$  for all values of  $k$  where  $I(k)$  is greater than the predetermined low threshold value and less than the predetermined high threshold value to derive a second sum  $q$ ; and

(v) computing a pixel brightness value of an output image  $I_o(x)$  at pixel position  $x$  by dividing the first sum  $p$  by the second sum  $q$ .

72. The method of claim 71, wherein the brightness value  $I(k)$  at pixel position  $k$  compared with the predetermined low threshold value and the predetermined high threshold value in step (i) is the captured image brightness value at pixel position  $k$ .

73. The method of claim 71, wherein the brightness value  $I(k)$  at pixel position  $k$  compared with the predetermined low threshold value and the predetermined high threshold value in step (i) is the captured image brightness value at pixel position  $k$  compensated by the inverse of response function of a light-sensing element having a sensitivity level corresponding to pixel position  $k$ .

74. The method of claim 73, wherein the captured image brightness value at pixel position  $k$  is compensated by the inverse of the response function of a light-sensing element having a sensitivity level corresponding to pixel position  $k$  by using the captured image brightness value at pixel position  $k$  to derive a respective index for a lookup table memory storing data representing the inverse of response functions of light-sensing elements having different ones of the plurality of sensitivity levels, and retrieving from the lookup table memory a compensated captured image brightness value  $I(k)$  corresponding to the respective index using lookup table data representing the inverse of the response function of a light-sensing element having the sensitivity level corresponding to pixel position  $k$ .

75. The method of claim 72, wherein the  $5 \times 1$  Gaussian kernel  $G$  has the form:

|     |     |      |     |     |
|-----|-----|------|-----|-----|
| 0.1 | 3.6 | 10.0 | 3.6 | 0.1 |
|-----|-----|------|-----|-----|

→  
 $k$

76. The method of claim 31, 35, 39, 49, 69 or 73, wherein the predetermined low threshold value is the noise level of a light-sensing element having the sensitivity level corresponding to the pixel position having the compensated brightness value being compared therewith compensated by the inverse of the response function of a light-sensing element having

5 the corresponding sensitivity level, and the predetermined high threshold value is the saturation  
6 or near saturation brightness value of a light-sensing element having the same sensitivity level.

1 77. A system for obtaining capturing a relatively high dynamic range image of a scene  
2 using a relatively low dynamic range image sensor adapted to be exposed to incident light from  
3 the scene for capturing an image thereof comprising:

4 (a) an image sensor having a multiplicity of light-sensing elements in an array, each light-  
5 sensing element having a particular one of a plurality of sensitivity levels to incident light in  
6 accordance with a predetermined sensitivity pattern for the array of light-sensing elements and a  
7 respective response function, each light-sensing element being responsive to incident light from  
8 the scene for producing a captured image brightness value at a corresponding one of a  
9 multiplicity of pixel positions of a pixel position array, whereby each one of the multiplicity of  
10 pixel positions corresponds to a particular one of the plurality of sensitivity levels of the light-  
11 sensing elements;

12 (b) a captured image memory for storing the captured image brightness values produced  
13 by the light-sensing elements at corresponding ones of the multiplicity of pixel positions of the  
14 pixel position array;

15 (c) an off-grid estimator for deriving from the captured image brightness values in the  
16 captured image memory respective estimated off-grid brightness values at a multiplicity of off-



17 grid positions located at respective interstices of the pixel position array so as to form a regular  
18 off-grid position array; and

19 (d) an output image generator for deriving pixel brightness values of an output image  
20 from the estimated off-grid brightness values.

1 78. The system of claim 77, wherein the array of light-sensing elements of the image  
2 sensor is a linear array for capturing a line image and the pixel position array is a linear array  
3 having the multiplicity of pixel positions located at respective regularly spaced positions in a  
4 pixel row so as to form a linear captured image brightness value array, the captured image  
5 memory for storing the captured image brightness values produced by the light-sensing elements.

1 79. The system of claim 78, wherein the off-grid positions of the off-grid position array  
2 are located between respective adjacent pairs of pixel positions of the linear pixel position array.

1 80. The system of claim 79, wherein the predetermined sensitivity pattern has a  
2 predetermined first sensitivity level and a predetermined second sensitivity level, and adjacent  
3 pixel positions of the linear pixel position array correspond to different ones of the predetermined  
4 first sensitivity level and the predetermined second sensitivity level.

1           81. The system of claim 77, wherein the array of light-sensing elements of the image  
2 sensor is a linear array and the pixel position array is a two-dimensional array having pixel  
3 positions at respective intersections of a plurality of regularly spaced pixel rows and a plurality  
4 of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and  
5 wherein the linear array of light-sensing elements of the image sensor is adapted to be  
6 sequentially exposed to successive regularly spaced linear regions of the scene in multiple  
7 exposures, each one of the exposures producing a respective linear captured image brightness  
8 value array, the respective linear captured image brightness value arrays produced by the  
9 multiple exposures being concatenated to form a two-dimensional captured image brightness  
10 value array having respective captured image brightness values at the pixel positions of the pixel  
11 position array, the concatenated linear captured image brightness value arrays being stored in the  
12 captured image memory as respective captured image brightness values at the pixel positions of  
13 the two-dimensional pixel position array.

1           82. The system of claim 81, wherein the off-grid positions of the off-grid position array  
2 are located at respective intersections of a plurality of regularly spaced intermediate columns and  
3 pixel rows, each one of the intermediate columns being parallel to the pixel columns and  
4 extending between a respective adjacent pair of the pixel columns.

1           83. The system of claim 82, wherein the predetermined sensitivity pattern has a first  
2           predetermined sensitivity level and a second predetermined sensitivity level, and wherein  
3           adjacent pixel positions in each one of the pixel rows correspond to different ones of the first and  
4           second predetermined sensitivity levels, and adjacent pixel positions in each one of the pixel  
5           columns correspond to the same one of the first and second predetermined sensitivity levels.

1           84. The system of claim 77, wherein the image sensor has a two-dimensional array of  
2           light-sensing elements and the multiplicity of pixel positions are located at respective  
3           intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel  
4           columns, the pixel rows being orthogonal to the pixel columns, the captured image memory for  
5           storing the captured image brightness values produced by the light-sensing elements at  
6           corresponding ones of the multiplicity of pixel positions of the pixel position array.

1           85. The system of claim 84 wherein the off-grid positions of the off-grid position array  
2           are located at respective intersections of a plurality of regularly spaced intermediate rows and a  
3           plurality of regularly spaced intermediate columns, each intermediate row being parallel to the  
4           pixel rows and extending between a respective adjacent pair of pixel rows and each intermediate  
5           column being parallel to the pixel columns and extending between a respective adjacent pair of  
6           pixel columns.

1           86. The system of claim 85, wherein the predetermined sensitivity pattern of the array of  
2 light-sensing elements has four different predetermined sensitivity levels and corresponds to a  
3 repetitive pattern of groups of four nearest neighbor pixel positions, each one of the four pixel  
4 positions in each group corresponding to a different one of the four predetermined sensitivity  
5 levels in a common predetermined positional order.

1           87. The system of claim 84, wherein the off-grid positions of the off-grid position array  
2 are located at respective intersections of a plurality of regularly spaced intermediate rows and the  
3 plurality of pixel columns, and at respective intersections of a plurality of regularly spaced  
4 intermediate columns and the pixel rows, each one of the intermediate rows being parallel to the  
5 pixel rows and extending between a respective adjacent pair of the pixel rows, each one of the  
6 intermediate columns being parallel to the pixel columns and extending between a respective  
7 adjacent pair of pixel columns.

1           88. The system of claim 87, wherein the predetermined sensitivity pattern of the array of  
2 light-sensing elements has first and second predetermined sensitivity levels, and wherein  
3 adjacent pixel positions in each one of the pixel rows and adjacent pixel positions in each one of  
4 the pixel columns correspond to different ones of the first and second predetermined sensitivity  
5 levels.

1           89. The system of claim 77, wherein the output image generator comprises an output  
2 image memory for storing the respective estimated off-grid brightness values derived by the off-  
3 grid estimator as the pixel brightness values of the output image.

1           90. The system of claim 77, wherein the output image generator comprises:

2           (a) an off-grid brightness value memory for storing the estimated off-grid brightness  
3 values derived by the off-grid estimator;

4           (b) an on-grid resampler for deriving from the estimated off-grid brightness values in the  
5 off-grid brightness value memory respective resampled on-grid brightness values at the pixel  
6 positions of the pixel position array; and

7           (c) an output image memory for storing the respective resampled on-grid brightness  
8 values derived by the on-grid resampler as the pixel brightness values of the output image.

1           91. The system of claim 77, wherein the off-grid estimator comprises:

2           (a) an off-grid position generator for providing the off-grid positions of the off-grid  
3 position array;

4           (b) a sensitivity pattern memory for storing data indicative of the sensitivity level  
5 corresponding to each one of the pixel positions of the pixel position array;

6           (c) a plurality of sensitivity level off-grid brightness value estimators each corresponding  
7 to a respective one of the plurality of sensitivity levels of the light-sensing elements, and

8 receiving off-grid positions from the off-grid position generator and sensitivity pattern data from  
9 the sensitivity pattern memory, each one of the sensitivity level off-grid brightness value  
10 estimators being responsive to an off-grid position received from the off-grid position generator  
11 and the sensitivity pattern data from the sensitivity pattern memory for deriving from the  
12 captured image brightness values in the captured image memory a respective sensitivity level  
13 off-grid brightness value for the corresponding sensitivity level at the received off-grid position;  
14 and

15 (d) an accumulator for combining the respective sensitivity level off-grid brightness  
16 values derived by the plurality of sensitivity level off-grid brightness value estimators for the  
17 corresponding sensitivity levels at each off-grid position received from the off-grid position  
18 generator to derive a respective estimated off-grid brightness value at each off-grid position  
19 received from the off-grid position generator.

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31 92. The system of claim 90, wherein the on-grid resampler comprises:

32 (i) a pixel position generator for providing the pixel positions of the pixel  
33 position array;

34 (ii) an interpolator for receiving pixel positions provided by the pixel position  
35 generator and being responsive to a pixel position received from the pixel position generator for  
36 deriving from the estimated off-grid brightness values in the off-grid brightness value memory a  
37 respective interpolated on-grid brightness value at the received pixel position; and

8 (iii) a response function compensator for compensating the respective interpolated  
9 on-grid brightness value derived by the interpolator at each pixel position received from the pixel  
10 position generator by the inverse of a combined response function of the light-sensing elements  
11 to derive a respective resampled on-grid brightness value at each pixel position received from the  
12 pixel position generator, the combined response function of the light-sensing elements being the  
13 sum of weighted response functions of light-sensing elements having different ones of the  
14 sensitivity levels, each one of the weighted response functions being a response function of a  
15 light-sensing element having a respective one of the sensitivity levels multiplied by a  
16 predetermined weighting factor for the respective one of the sensitivity levels.

1 93. The system of claim 92, wherein the response function compensator comprises a  
2 lookup table memory storing data representing the inverse of the combined response function of  
3 the light-sensing elements and a mapper for deriving from the respective interpolated on-grid  
4 brightness value derived by the interpolator at a received pixel position a respective index for the  
5 lookup table memory and providing a data value in the lookup table memory corresponding to  
6 the respective index to the output image memory, the data value being the pixel brightness value  
7 of the output image at the received pixel position.

1 94. The system of claim 91, wherein the accumulator comprises an adder for adding the  
2 sensitivity level off-grid brightness values derived by the plurality of sensitivity level off-grid

3 brightness value estimator for corresponding sensitivity levels at each received off-grid position  
4 to derive the respective estimated off-grid brightness value at each off-grid positions received  
5 from the off-grid position generator.

1 95. The system of claim 91, wherein the accumulator comprises a weighting factor  
2 memory for storing a plurality of predetermined weighting factors each corresponding to a  
3 different one of the plurality of sensitivity levels of the light-sensing elements, a plurality of  
4 multipliers each for multiplying the sensitivity level off-grid brightness value corresponding to a  
5 respective one of the sensitivity levels at a received off-grid position by the weighting factor  
6 corresponding to the respective one of the sensitivity levels to provide a respective weighted  
7 sensitivity level off-grid brightness value for the corresponding sensitivity level at the received  
8 off-grid position, and an adder for summing the respective weighted sensitivity level off-grid  
9 brightness values provided by the plurality of multipliers to derive a respective estimated off-grid  
10 brightness value at the received off-grid position received from the off-grid position generator.

1 96. The system of claim 77, wherein the off-grid estimator comprises:

2 (a) an off-grid position generator for providing the off-grid positions of the off-grid  
3 position array;

4 (b) a sensitivity pattern memory for storing data indicative of the sensitivity level  
5 corresponding to each one of the pixel positions of the pixel position array;



6 (c) a plurality of sensitivity level off-grid brightness value estimators, each  
7 corresponding to a respective one of the sensitivity levels, for receiving off-grid positions from  
8 the off-grid position generator and sensitivity pattern data from the sensitivity pattern memory,  
9 each one of the plurality of sensitivity level off-grid brightness value estimators being responsive  
10 to an off-grid position received from the off-grid position generator and the sensitivity pattern  
11 data from the sensitivity pattern memory for deriving from the captured image brightness values  
12 in the captured image memory a respective sensitivity level off-grid brightness value for the  
13 corresponding sensitivity level at the received off-grid position;

14 (d) an accumulator for combining the respective sensitivity level off-grid brightness  
15 values derived by the plurality of sensitivity level off-grid brightness value estimator for the  
16 corresponding sensitivity levels at each off-grid position received from the off-grid position  
17 generator to derive a respective combined sensitivity level off-grid brightness value at each off-  
18 grid position received from the off-grid position generator; and

19 (e) a response function compensator for compensating the respective combined sensitivity  
20 level off-grid brightness value at each off-grid position received from the off-grid position  
21 generator by the inverse of a combined response function of the light-sensing elements to derive  
22 a respective estimated off-grid brightness value at each off-grid position received from the off-  
23 grid position generator, the combined response function being the sum of weighted response  
24 functions of light-sensing elements having different ones of the plurality of sensitivity levels,  
25 each one of the weighted response functions being a response function of a light-sensing element

26 having a respective one of the sensitivity levels multiplied by a predetermined weighting factor  
27 for the respective one of the sensitivity levels.

1 97. The system of claim 96, wherein the response function compensator comprises a  
2 lookup table memory storing lookup table data representing the inverse of the combined response  
3 function of the light-sensing elements, and a mapper for deriving from the respective combined  
4 sensitivity level off-grid brightness value at each off-grid position received from the off-grid  
5 position generator a respective index for the lookup table memory and providing a data value in  
6 the lookup table memory corresponding to the respective index as the respective estimated off-  
7 grid brightness value at the off-grid position received from the off-grid position generator.

1 98. The system of claim 96, wherein the output image generator comprises:

2 (a) an off-grid brightness value memory for storing the respective estimated off-grid  
3 brightness value derived by the response function compensator at each off-grid position received  
4 from the off-grid position generator;

5 (b) an on-grid resampler for deriving from the estimated off-grid brightness values in the  
6 off-grid brightness value memory respective resampled on-grid brightness values at the pixel  
7 positions of the pixel position array; and

8 (c) an output image memory for storing the respective resampled on-grid brightness  
9 values derived by the on-grid resampler as the pixel brightness values of the output image,

and wherein the on-grid resampler comprises:

(i) a pixel position generator for providing pixel positions of the pixel position array; and

(ii) an interpolator for receiving pixel positions provided by the pixel position generator and being responsive to a pixel position received from the pixel position generator for deriving from the estimated off-grid brightness values in the off-grid brightness value memory a respective resampled on-grid brightness value at the received pixel position.

99. The system of claim 96, wherein the accumulator of the off-grid estimator comprises an adder for adding the respective sensitivity level off-grid brightness values derived by the plurality of sensitivity level off-grid brightness value estimators for the corresponding sensitivity levels at each off-grid position received from the off-grid position generator to provide the combined sensitivity level off-grid brightness values at each off-grid position received from the off-grid position generator.

100. The system of claim 96, wherein the accumulator of the off-grid estimator comprises a weighting factor memory for storing a plurality of predetermined weighting factors each corresponding to a different one of the plurality of sensitivity levels of the light-sensing elements, a plurality of multipliers each for multiplying the sensitivity level off-grid brightness value corresponding to a respective one of the sensitivity levels at a received off-grid position by

6 the weighting factor corresponding to the respective one of the sensitivity levels to provide a  
7 weighted sensitivity level off-grid brightness value for the corresponding sensitivity level at the  
8 off-grid position received from the off-grid position generator, and an adder for summing the  
9 weighted sensitivity level off-grid brightness values at the received off-grid position provided by  
10 the plurality of multipliers to derive the combined sensitivity level off-grid brightness value at  
11 the off-grid positions received from the off-grid position generator.

101. The system of claim 100, wherein the array of light-sensing elements of the image  
sensor is a linear array and the pixel position array is a linear array having a multiplicity of pixel  
positions at respective regularly spaced pixel positions in a pixel row, and wherein the off-grid  
positions of the off-grid position array are each located between a respective adjacent pair of  
pixel positions of the pixel position array and the sensitivity level off-grid brightness values  
derived by the plurality of sensitivity level off-grid brightness value estimators for an off-grid  
position received from the off-grid position generator are respective captured image brightness  
values at a predefined number of pixel positions that are nearest neighbors to the received off-  
grid position, each one of the predefined number of nearest neighbor pixel positions  
corresponding to a different one of the plurality of sensitivity levels of the light-sensing  
elements.

102. The system of claim 101, wherein each one of the off-grid positions of the off-grid position array is located midway between a respective adjacent pair of pixel positions of the linear pixel position array and the predetermined sensitivity pattern of the light-sensing elements has a first and a second predetermined sensitivity level, and wherein the combined sensitivity level off-grid brightness value at an off-grid position  $x'$  received from the off-grid position generator is expressed as

$$B(x') = W_1 I_c(x' - 0.5) + W_2 I_c(x' + 0.5),$$

where  $B(x')$  is the combined sensitivity level off-grid brightness value at the received off-grid position  $x'$ ,  $W_1$  is the weighting factor for the sensitivity level corresponding to pixel position  $(x' - 0.5)$ ,  $W_2$  is the weighting factor for the sensitivity level corresponding to pixel position  $(x' + 0.5)$ ,  $I_c(x' - 0.5)$  is the captured image brightness value at pixel position  $(x' - 0.5)$  and  $I_c(x' + 0.5)$  is the captured image brightness value at pixel position  $(x' + 0.5)$ , and the combined response function of the light-sensing elements is expressed as

$$S(E) = W_1 P_1(E) + W_2 P_2(E),$$

where  $P_1(E)$  is the radiometric response function of a light-sensing element having the sensitivity level corresponding to pixel position  $(x' - 0.5)$  and  $P_2(E)$  is the radiometric response function of a light-sensing element having the sensitivity level corresponding to pixel position  $(x' + 0.5)$ .

103. The system of claim 100, wherein the image sensor has a two-dimensional array of light-sensing elements and the multiplicity of pixel positions are located at respective

3 intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel  
4 columns defining a two-dimensional pixel position array, the pixel rows being orthogonal to the  
5 pixel columns, the multiplicity of off-grid positions are located at respective intersections of a  
6 plurality of regularly spaced intermediate rows and a plurality of regularly spaced intermediate  
7 columns, each one of the intermediate rows being parallel to the pixel rows and extending  
8 between a respective adjacent pair of the pixel rows, each one of the intermediate columns being  
9 parallel to the pixel columns and extending between a respective adjacent pair of the pixel  
10 columns.

104. The system of claim 103, wherein the predetermined sensitivity pattern of the array  
of light-sensing elements corresponds to a pixel position array having repetitive disposed groups  
of four nearest neighbor pixel positions, where each one of the four nearest neighbor pixel  
positions in each group corresponds to a respective one of four predetermined sensitivity levels  
in a common predetermined positional order.

105. The system of claim 100, wherein the image sensor has a two-dimensional array of  
light-sensing elements and the multiplicity of pixel positions are located at respective  
intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel  
columns defining a two-dimensional pixel position array, the pixel rows being orthogonal to the  
pixel columns, and wherein the multiplicity of off-grid positions are located at respective

6 intersections of a plurality of regularly spaced intermediate rows and the pixel columns, and at  
7 respective intersections of a plurality of regularly spaced intermediate columns and the pixel  
8 rows, each one of the intermediate rows being parallel to the pixel rows and extending between a  
9 respective adjacent pair of the pixel rows, each one of the intermediate columns being parallel to  
10 the pixel columns and extending between a respective adjacent pair of the pixel columns.

1 106. The system of claim 100, wherein the predetermined sensitivity pattern of the array  
2 of light-sensing elements has a first and a second predetermined sensitivity level, and adjacent  
3 pixel positions in each one of the pixel rows and adjacent pixel positions in each one of the pixel  
4 columns correspond to different ones of the predetermined first and second sensitivity levels.

1 107. The system of claim 100, wherein the array of light-sensing elements of the image  
2 sensor is a linear array and the multiplicity of pixel positions are located at respective regularly  
3 spaced pixel positions in a pixel row so as to form a linear captured image brightness value array,  
4 and wherein the linear array of light-sensing elements of the image sensor is adapted to be  
5 sequentially exposed to successive regularly spaced linear regions of the scene in multiple  
6 exposures, each one of the exposures producing a respective linear captured image brightness  
7 value array, the respective linear captured image brightness value arrays produced by the  
8 multiple exposures being concatenated to form a two-dimensional captured image brightness  
9 value array having respective captured image brightness values at pixel positions of a pixel

10 position array located at respective intersections of a plurality of regularly spaced pixel rows and  
11 a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel  
12 columns, and wherein the multiplicity of off-grid positions are located at respective intersections  
13 of the pixel rows and a plurality of regularly spaced intermediate columns, each one of the  
14 intermediate columns being parallel to the pixel columns and extending between a respective  
15 adjacent pair of the pixel columns.

108. The system of claim 107, wherein the predetermined sensitivity pattern of the array  
of light-sensing elements has a first and a second predetermined sensitivity level, and wherein  
adjacent pixel positions in each pixel row correspond to different ones of the first and the second  
predetermined sensitivity levels and adjacent pixel positions in each pixel column correspond to  
the same one of the first and the second predetermined sensitivity levels.

109. The apparatus of claim 91 or 96, wherein each one of the sensitivity level off-grid  
brightness value estimators is responsive to an off-grid position received from the off-grid  
position generator and the data indicative of the sensitivity level corresponding to each one of the  
pixel positions from the sensitivity pattern memory for determining a pixel position  
corresponding to the same sensitivity level as the sensitivity level off-grid brightness value  
estimator and located nearest the received off-grid position, and for estimating a sensitivity level  
off-grid brightness value at the received off-grid position to be equal to the captured image



8 brightness value at the nearest pixel position corresponding to the same sensitivity level as the  
9 sensitivity level off-grid brightness value estimator.

1 110. The method of claim 92, wherein the interpolator is responsive to a pixel position  
2 received from the pixel position generator for computing a product of the estimated off-grid  
3 brightness values at a predetermined number of off-grid positions that are nearest neighbors to  
4 the received pixel position and an interpolation kernel having the same dimensions as the  
5 predetermined number of off-grid positions.

1 111. The apparatus of claim 92, wherein the pixel positions provided by the pixel  
2 position generator are located at respective intersections of a plurality of regularly spaced pixel  
3 rows and a plurality of regularly spaced pixel columns, the pixel columns being orthogonal to the  
4 pixel rows, and the off-grid positions provided by the off-grid position generator are located at  
5 respective intersections of a plurality of regularly spaced intermediate rows and a plurality of  
6 regularly spaced intermediate columns, each one of the intermediate rows being parallel to the  
7 pixel rows and extending medially between a respective adjacent pair of the pixel rows, each  
8 intermediate column being parallel to the pixel columns and extending medially between a  
9 respective adjacent pair of the pixel columns, and wherein the interpolator derives the  
10 interpolated on-grid brightness values at each one of the pixel positions (x,y) received from the  
11 pixel position generator using the relation

$$I(x-2, y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x-1.5 + i, y-1.5 + j) \phi_{ij},$$

where x has values from 2.5 to xSize - 2.5, y has values from 2.5 to ySize - 2.5, I(x-2, y-2) is the interpolated on-grid brightness value at pixel position (x-2, y-2), B(x-1.5+i, y-1.5+j) is the off-grid brightness value at off-grid position (x-1.5+i, y-1.5+j),  $\phi_{ij}$  is the value of a 4 × 4 cubic interpolation kernel  $\phi$  at indices i and j, indices i and j each has values from 0 to 3, xSize is the dimension of the captured image in the direction of the pixel rows, and ySize is the dimension of the captured image in the direction of the pixel columns.

112. The apparatus of claim 98, wherein the pixel positions provided by the pixel position generator are located at respective intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and the off-grid positions provided by the off-grid position generator are located at respective intersections of a plurality of regularly spaced intermediate rows and a plurality of regularly spaced intermediate columns, each one of the intermediate rows being parallel to the pixel rows and extending medially between a respective adjacent pair of the pixel rows, each one of the intermediate columns being parallel to the pixel columns and extending medially between a respective adjacent pair of the pixel columns, and wherein the interpolator derives the

resampled on-grid brightness values at each one of the pixel positions (x,y) received from the pixel position generator by the relation

$$I(x-2,y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x-1.5 + i, y-1.5 + j)\phi_{ij},$$

where x has values from 2.5 to xSize-2.5, y has values from 2.5 to ySize-2.5, I(x-2, y-2) is the resampled on-grid brightness value at pixel position (x-2, y-2), B(x-1.5+i,y-1.5+j) is the off-grid brightness value at off-grid position (x-1.5+i, y-1.5+j),  $\phi_{ij}$  is the value of a 4 × 4 cubic interpolation kernel  $\phi$  at indices i and j, the indices i and j each have values from 0 to 3, xSize is the dimension of the captured image in the direction of the pixel rows, and ySize is the dimension of the captured image in the direction of the pixel columns.

113. The apparatus of claim 92, wherein the pixel positions provided by the pixel position generator are located at respective intersections of a plurality of regularly spaced pixel columns and a plurality of regularly spaced pixel rows, the pixel rows being orthogonal to the pixel columns, and the off-grid positions provided by the off-grid generator are located at respective intersections of a plurality of regularly spaced intermediate rows and the pixel columns and at respective intersections of a plurality of regularly spaced intermediate columns and the pixel rows, each one of the intermediate rows being parallel to the pixel rows and extending medially between a respective adjacent pair of the pixel rows, each one of the

intermediate columns being parallel to the pixel columns and extending medially between a respective adjacent pair of the pixel columns, and wherein the interpolator derives the interpolated on-grid brightness values at each one of the pixel positions (x,y) received from the pixel position generator using the relation

$$I(x-2,y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x+0.5i-0.5j, y-1.5+0.5i+0.5j)\phi_{ij},$$

where x has values from 2.5 to xSize - 2.5, y has values from 2.5 to ySize - 2.5,  $I(x-2, y-2)$  is the interpolated on-grid brightness value at pixel position (x-2, y-2),  $B(x+0.5i-0.5j, y-1.5+0.5i+0.5j)$  is the off-grid brightness value at off-grid position (x+0.5i-0.5j, y-1.5+0.5i+0.5j),  $\phi_{ij}$  is the value of a  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices i and j, indices i and j each have values from 0 to 3, xSize is the dimension of the captured image in the direction of the pixel rows, and ySize is the dimension of the captured image in the direction of the pixel columns.

114. The apparatus of claim 98, wherein the pixel positions provided by the pixel position generator are located at respective intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and the off-grid positions provided by the off-grid position generator are located at respective intersections of a plurality of regularly spaced intermediate rows and the pixel

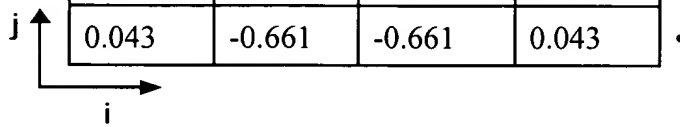
columns and at respective intersections of a plurality of regularly spaced intermediate columns and the pixel rows, each one of the intermediate rows being parallel to the pixel rows and extending medially between a respective adjacent pair of the pixel rows, each one of the intermediate columns being parallel to the pixel columns and extending medially between a respective adjacent pair of the pixel columns, and wherein the interpolator derives the resampled on-grid brightness values at each one of the pixel positions (x,y) received from the pixel position generator using the relation

$$I(x-2,y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x+0.5i-0.5j, y-1.5+0.5i+0.5j)\phi_{ij},$$

where x has values from 2.5 to xSize-2.5, y has values from 2.5 to ySize-2.5, I(x-2,y-2) is the resampled on-grid brightness value at pixel position (x-2,y-2), B(x+0.5i-0.5j, y-1.5+0.5i+0.5j) is the off-grid brightness value at the off-grid position (x+0.5i-0.5j, y-1.5+0.5i+0.5j),  $\phi_{ij}$  is the value of a 4 × 4 cubic interpolation kernel  $\phi$  at indices i and j, indices i and j each have values from 0 to 3, xSize is the dimension of the captured image in the direction of the pixel rows, and ySize is dimension of the captured image in the direction of the pixel columns.

115. The method of claim 111 or 112, wherein the  $4 \times 4$  cubic interpolation kernel  $\phi$  has the form:

|        |        |        |        |
|--------|--------|--------|--------|
| 0.043  | -0.661 | -0.661 | 0.043  |
| -0.661 | 10.28  | 10.28  | -0.661 |
| -0.661 | 10.28  | 10.28  | -0.661 |
| 0.043  | -0.661 | -0.661 | 0.043  |



116. The system of claim 98, wherein the pixel positions provided by the pixel position generator are located at respective regularly spaced pixel positions in a pixel row defining a linear pixel position array and the off-grid positions provided by the off-grid position generator are each located midway between a respective adjacent pair of pixel positions of the pixel position row, and wherein the interpolator derives the resampled on-grid brightness values at each one of the pixel positions  $x$  received from the pixel position generator using the relation

$$I_o(x - 3) = \sum_{k=-1.5}^{k=1.5} B(x + k)\psi(k),$$

where  $x$  has values from 3.5 to  $xSize - 3.5$ ,  $I_o(x - 3)$  is the resampled on-grid brightness value at pixel position  $(x - 3)$ ,  $B(x + k)$  is the estimated off-grid brightness value at off-grid position  $(x + k)$ ,  $k$  is a position of a  $4 \times 1$  cubic interpolation kernel  $\psi$ ,  $\psi(k)$  is the value of the cubic interpolation kernel  $\psi$  at position  $k$ , the position  $k$  has values from  $-1.5$  to  $1.5$ , and  $xSize$  is the dimension of the captured line image.

117. The system of claim 116, wherein the  $4 \times 1$  cubic interpolation kernel  $x$  has the form:

|       |       |       |       |
|-------|-------|-------|-------|
| -0.96 | 13.44 | 13.44 | -0.96 |
|-------|-------|-------|-------|

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k

118. The apparatus of claim 77, wherein the image sensor is an integrated circuit charge coupled device having an array of photodiodes in spaced orthogonal rows and columns, each one of the photodiodes having a light-sensing surface adapted to be exposed to incident light and being operatively biased to store photogenerated charge therein, the charge coupled device having respective integrated lenses formed over the photosensitive surfaces of predetermined ones of the photodiodes, each integrated lens concentrating the incident light onto the respective light-sensing surface, whereby the sensitivity level of each one of the photodiodes is determined by whether or not an integrated lens is formed over the light-sensing surface thereof.

119. The apparatus of claim 77, wherein the image sensor is an integrated circuit charge coupled device having an array of photodiodes arranged in spaced orthogonal rows and columns, each one of the photodiodes having a light-sensing surface adapted to be exposed to incident light and being operatively biased to store photogenerated charge therein, each one of the photodiodes having an integrated light filter formed above the light-sensing surface thereof, the transparency of each integrated light filter being fixed during fabrication of the charge coupled

7 device, whereby the sensitivity level of each one of the photodiodes in the array is determined by  
8 the transparency of the integrated light filter above the light-sensing surface thereof.

1 120. The system of claim 77, wherein the image sensor is an integrated circuit charge  
2 coupled device having an array of photodiodes arranged in spaced orthogonal rows and columns,  
3 each one of the photodiodes having a light-sensing surface adapted to be exposed to incident  
4 light and being operatively biased to store photogenerated charge therein, the charge coupled  
5 device being formed with an opaque layer overlying the array of photodiodes with a respective  
6 aperture formed in the opaque layer above the light-sensing surface of each one of the  
7 photodiodes, the respective size of the aperture above the light-sensing surface of each one of the  
8 photodiodes being fixed during fabrication of the charge coupled device, whereby the sensitivity  
9 level of each one of the photodiodes in the array is determined by the size of the aperture above  
10 the light-sensing surface thereof.

1 121. The system of claim 77, wherein the image sensor is an integrated circuit charge  
2 coupled device having a multiplicity of photodiodes in an array of spaced orthogonal rows and  
3 columns, each one of the photodiodes having a light-sensing surface adapted to be exposed to  
4 incident light and being operatively biased to store photogenerated charge therein, the charge  
5 coupled device having an interline structure in which the columns of photodiodes are each  
6 disposed adjacent a corresponding vertical shift register, each photodiode having an associated



7 transfer gate electrode for controlling the transfer of stored photogenerated charge from the  
8 photodiode to the corresponding vertical shift register, the stored photogenerated charge in each  
9 one of the photodiodes being operatively periodically removed by the application of a periodic  
10 reset pulse to the device, the photogenerated charge stored in each one of the photodiodes being  
11 operatively transferred to a respective stage of the corresponding vertical shift register by the  
12 application of a transfer trigger pulse to the associated transfer gate electrode and being  
13 accumulated therein for an exposure interval, the transfer trigger pulse being applied immediately  
14 preceding a reset pulse, the respective transfer trigger pulses being operatively applied to the  
15 transfer gate electrodes associated with the photodiodes in the array at predetermined  
16 frequencies, whereby the sensitivity level of each one of the photodiodes in the array is  
17 determined by the frequency of transfer trigger pulses applied to the transfer gate electrode  
18 associated therewith.

1 122. The system of claim 77, wherein the off-grid estimator comprises:

- 2 (a) a pixel position generator for providing the pixel positions of the pixel position array;
- 3 (b) a sensitivity pattern memory for storing the sensitivity level corresponding to each
- 4 one of the pixel positions;
- 5 (c) a response function compensator receiving pixel positions of the pixel position array
- 6 from the pixel position generator, data indicative of the sensitivity levels corresponding to the
- 7 received pixel positions from the sensitivity pattern memory and captured image brightness

8 values at the received pixel positions from the captured image memory, and being responsive to a  
9 pixel position received from the pixel position generator and data indicative of the sensitivity  
10 level corresponding to the received pixel position for retrieving from the captured image  
11 memory the captured image brightness value at the received pixel position and for compensating  
12 the retrieved captured image brightness value at the received pixel positions by the inverse of a  
13 response function of a light-sensing element having the sensitivity level corresponding to the  
14 received pixel position to provide a respective compensated brightness value at the pixel position  
15 received from the pixel position generator;

16 (d) a compensated on-grid brightness value memory for storing respective compensated  
17 captured image brightness values derived by the response function compensator;

18 (e) an off-grid position generator for providing the off-grid positions of the off-grid  
19 position array;

20 (f) a pseudoinverse estimator receiving off-grid positions from the off-grid position  
21 generator and being responsive to an off-grid position received from the off-grid position  
22 generator for deriving from the compensated captured image brightness values in the  
23 compensated on-grid brightness value memory a respective estimated off-grid brightness value at  
24 the off-grid positions received from the off-grid position generator.

1 123. The system of claim 122, wherein the output image generator comprises

2 (i) an off-grid brightness value memory for storing the respective estimated off-  
3 grid brightness values derived by the pseudoinverse estimator;

4 (ii) an on-grid resampler for deriving from the estimated off-grid brightness  
5 values in the off-grid brightness value memory respective on-grid resampled brightness values at  
6 the pixel positions of the pixel position array; and

7 (iii) an output image memory for storing the respective resampled on-grid  
8 brightness values derived by the on-grid resampler as pixel brightness values of the output  
9 image, and wherein the on-grid resampler comprises:

10 (1) a second pixel position generator for providing the pixel positions of  
11 the pixel position array; and

12 (2) an interpolator receiving pixel positions from the pixel position  
13 generator and being responsive to a pixel position received from the second pixel position  
14 generator for deriving from the estimated off-grid brightness values in the off-grid brightness  
15 value memory the resampled on-grid brightness value at the pixel position received from the  
16 second pixel position generator.

1 124. The system of claim 122, wherein the response function compensator comprises a  
2 lookup table memory storing separate lookup table data representing the inverse of respective  
3 response functions of light-sensing elements having different ones of the plurality of sensitivity  
4 levels, and a mapper receiving from the captured image memory the captured image brightness

5 value at the pixel position received from the first pixel position generator for deriving therefrom  
6 a respective index for the lookup table data representing the inverse of the response function of a  
7 light-sensing element having the sensitivity level corresponding to the received pixel position,  
8 and providing a compensated on-grid brightness value corresponding to the index to the  
9 compensated on-grid brightness value memory.

1 125. The system of claim 122, wherein the pseudoinverse estimator comprises means  
2 responsive to an off-grid positions received from the off-grid position generator for retrieving  
3 from the compensated on-grid brightness value memory respective compensated on-grid  
4 brightness values at a predetermined number of pixel positions that are nearest neighbors to the  
5 received off-grid position, a comparator for comparing each one of the respective compensated  
6 on-grid brightness values at the nearest neighbor pixel positions to a predetermined low threshold  
7 value and a predetermined high threshold value, an adder means for computing a sum of  
8 compensated on-grid brightness values at the nearest neighbor pixel positions that are greater  
9 than the predetermined low threshold value and less than the predetermined high threshold value,  
10 and a divider for deriving the estimated off-grid brightness value at the received off-grid position  
11 by dividing the sum computed by the adder by the number of compensated on-grid brightness  
12 values included in the sum.

1           126. The system according to claim 122, wherein the pixel positions provided by the  
2 pixel position generator are located at respective intersections of a plurality of regularly spaced  
3 pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to  
4 the pixel columns, and the off-grid positions provided by the off-grid position generator are  
5 located at respective intersections of a plurality of regularly spaced intermediate rows and a  
6 plurality of regularly spaced intermediate columns, each one of the intermediate rows being  
7 parallel to the pixel rows and extending medially between a respective adjacent pair of the pixel  
8 rows, each intermediate column being parallel to the pixel columns and extending medially  
9 between a respective adjacent pair of pixel columns, and wherein the off-grid positions provided  
10 by the off-grid position generator have coordinates  $(x', y')$  where  $x'$  has values from 1 to  $xSize-1$   
11 and  $y'$  has values from 1 to  $ySize-1$ ,  $xSize$  being the dimension of the captured image in the  
12 direction of the pixel rows and  $ySize$  being the dimension of the captured image in the direction  
13 of the pixel columns.

1           127. The system of claim 126, wherein the predetermined sensitivity pattern of the array  
2 of light-sensing elements corresponds to a pixel position array having repetitively disposed  
3 groups of four nearest neighbor pixel positions, where each of the four nearest neighbor pixel  
4 positions in each group corresponds to a respective one of four predetermined sensitivity levels  
5 in a common predetermined positional order.

128. The system of claim 126, wherein the pseudoinverse estimator for estimating the respective brightness value at an off-grid position  $(x', y')$  received from the off-grid position generator comprises:

- (i) a memory for storing a  $4 \times 4$  cubic interpolator kernel  $\phi$ ;
- (ii) a comparator for comparing the compensated on-grid brightness value at each one of sixteen pixel positions  $(u, v)$  that are nearest neighbors to the received off-grid position  $(x', y')$  with a predetermined low threshold value and a predetermined high threshold value;
- (iii) first computing means for calculating the indices  $i$  and  $j$  of the  $4 \times 4$  cubic interpolation kernel  $\phi$  using the relations  $i = x' - u - 1.5$  and  $j = y' - v - 1.5$  for each one of the sixteen nearest neighbor pixel positions  $(u, v)$  having a compensated on-grid brightness value  $I(u, v)$  that is greater than the predetermined low threshold value and less than the predetermined high threshold value, where  $u$  has values from  $x' - 1.5$  to  $x' + 1.5$  and  $v$  has values from  $y' - 1.5$  to  $y' + 1.5$ ;
- (iv) second computing means for calculating the quantity

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2}$$

for each compensated on-grid brightness value  $I(u, v)$  at the sixteen nearest neighbor pixel positions  $(u, v)$  that is greater than the predetermined threshold value and less than the

predetermined threshold value using the indices i and j calculated by the first computing means,  
 where  $\phi_{mn}$  is the value of the  $4 \times 4$  interpolating kernel  $\phi$  at indices m and n;

(v) third computing means for calculating the quantities  $\phi_{ij}^2$ , for values of i and j  
 calculated by the first computing means;

(vi) first adder for adding the quantities

$$\phi_{ij}^2 \frac{\phi_{ji} I(u,v)}{\sum_{ab} \phi_{ab}^2}$$

calculated by the second computing means to derive a first sum s;

(vii) second adder for adding the quantities  $\phi_{ij}^2$  calculated by the third computing  
 means to derive a second sum w; and

(viii) a divider for deriving the estimated off-grid brightness value at the received  
 off-grid position (x',y') by dividing the first sum s by the second sum w.

129. The system according to claim 122, wherein the pixel positions provided by the  
 pixel position generator are located at respective intersections of a plurality of regularly spaced  
 pixel rows and a plurality of regularly spaced pixel columns, and the off-grid positions provided  
 by the off-grid position generator are located at respective intersections of a plurality of regularly  
 spaced intermediate rows and the pixel columns, and at respective intersections of a plurality of  
 regularly spaced intermediate columns and the pixel rows, each one of the intermediate rows

7 being parallel to the pixel rows and extending medially between a respective adjacent pair of the  
 8 pixel rows, each intermediate column being parallel to the pixel columns and extending medially  
 9 between a respective adjacent pair of the pixel columns, the off-grid positions provided by the  
 10 off-grid position generator having coordinates  $(x'y')$  where  $x'$  has values from 1 to  $xSize-1$  and  
 11  $y'$  has values from 0.5 to  $ySize-0.5$  for off-grid positions located at respective intersections of  
 12 the pixel rows and the intermediate columns, and where  $x'$  has values from 0.5 to  $ySize-0.5$  and  
 13  $y'$  has values from 1 to  $ySize-1$  for off-grid positions located at respective intersections of the  
 14 pixel columns and the intermediate rows,  $xSize$  being the dimension of the captured image in the  
 15 direction of the pixel rows and  $ySize$  being the dimension of the captured image in the direction  
 16 of the pixel columns.

130. The system of claim 129, wherein the predetermined sensitivity pattern of the array  
 of light-sensing elements has first and second predetermined sensitivity levels, and adjacent pixel  
 positions in each pixel row and adjacent pixel positions in each pixel column correspond to  
 different ones of the first and second predetermined sensitivity levels.

131. The system of claim 129, wherein the pseudoinverse estimator for estimating the  
 respective off-grid brightness value at an off-grid position  $(x',y')$  received from the off-grid  
 position generator comprises:

(i) a memory for storing a  $4 \times 4$  cubic interpolation kernel  $\phi$ ;



(ii) first computing means responsive to an off-grid position  $(x', y')$  received from the off-grid position generator for computing coordinates  $(u, v)$  using the relations  $u = x' + 0.5i - 0.5j$  and  $v = y' - 1.5 + 0.5i + 0.5j$ , where  $i$  and  $j$  are indices of the  $4 \times 4$  cubic interpolation kernel  $\phi$ , and each one of the indices  $i$  and  $j$  has values from 0 to 3;

(iii) means responsive to each pair of coordinates  $(u, v)$  computed by the first computing means for determining whether the coordinates  $(u, v)$  are those of a pixel position;

(iv) a comparator responsive to the coordinates  $(u, v)$  being coordinates of a pixel position for comparing the compensated on-grid brightness value  $I(u, v)$  at the pixel position  $(u, v)$  with a predetermined low threshold value and a predetermined high threshold value;

(v) second computing means responsive to the coordinates  $(u, v)$  being the coordinates of a pixel position and the compensated on-grid brightness value  $I(u, v)$  at the pixel position  $(u, v)$  being greater than a predetermined low threshold value and less than a predetermined high threshold value for calculating the quantity

$$\phi_{ij}^2 \frac{\phi_{ji} I(u, v)}{\sum_{ab} \phi_{ab}^2},$$

where the values of  $i$  and  $j$  are those used by the first computing means to calculate the coordinate  $(u, v)$ , and  $\phi_{mn}$  is the value of the  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices  $m$  and  $n$ ;

(vi) third computing means for calculating the quantity  $\phi_{ij}^2$  for values of  $i$  and  $j$  used by the first computing means to calculate pixel position coordinates  $(u, v)$  at which the compensated

on-grid brightness value  $I(u,v)$  is greater than the predetermined low threshold value and less than the predetermined high threshold value;

(vii) a first adder for adding the quantities

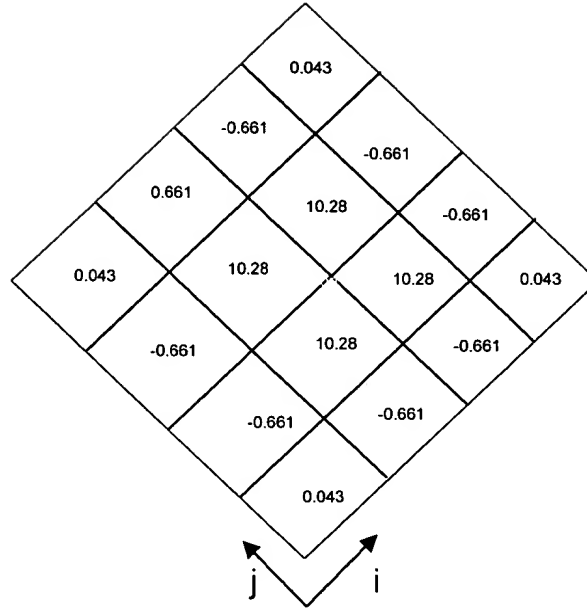
$$\phi_{ij}^2 \frac{\phi_{ji} I(u,v)}{\sum_{ab} \phi_{ab}^2}$$

calculated by the second computing means to derive a first sum  $s$ ;

(viii) a second adder for adding the quantities  $\phi_{ij}^2$  calculated by the third computing means to derive a second sum  $w$ ; and

(ix) a divider for deriving the estimated off-grid brightness value at the off-grid position  $(x',y')$  received from the off-grid position generator by dividing the first sum  $s$  by the second sum  $w$ .

132. The system of claim 131, wherein the  $4 \times 4$  cubic interpolation kernel  $\phi$  has the form:



1 133. The system of claim 122, wherein the pixel positions provided by the pixel position  
2 generator are located at respective regularly spaced pixel positions in a linear pixel position array  
3 and the off-grid positions provided by the off-grid position generator are each located midway  
4 between a respective adjacent pair of pixel positions of the linear pixel position array, and  
5 wherein the predetermined sensitivity pattern of the light-sensing elements has a first and a  
6 second predetermined sensitivity level, and adjacent pixel positions of the linear pixel position  
7 array correspond to different ones of the first and second predetermined sensitivity levels.

1 134. The system of claim 133, wherein the pixel positions provided by the pixel position  
2 generator has values from 0.5 to  $xSize-0.5$ , where  $xSize$  is the dimension of the captured line  
3 image, and the off-grid positions provided by the off-grid position generator have values from 2  
4 to  $xSize-2$ .

1 135. The system of claim 134, wherein the pseudoinverse estimator for estimating the  
2 respective brightness values at an off-grid position  $x'$  received from the off-grid position  
3 generator comprises:

4 (i) a memory for storing a  $4 \times 1$  Gaussian interpolation kernel  $G$ ;

5 (ii) a comparator for comparing the compensated on-grid brightness value  $I(k)$  at each one  
6 of four pixel positions  $k$  that are nearest neighbors to the received off-grid position  $x'$  with a  
7 predetermined low threshold value and a predetermined high threshold value, where  $k$  has values  
8 from  $x'-1.5$  to  $x'+1.5$ ;

9 (iii) first computing means for calculating the quantity  $I(k)G(k-x')$  for each one of the  
10 compensated on-grid brightness values  $I(k)$  at the four nearest neighbor pixel positions  $k$  that is  
11 greater than the predetermined low threshold value and less than the predetermined high threshold  
12 value, where  $G(k-x')$  is the value of the Gaussian interpolation kernel  $G$  at position  $(k-x')$ ;

13 (iv) a first adder for adding the quantities  $I(k)G(k-x')$  for all values of  $I(k)$  greater than  
14 the predetermined low threshold value and less than the predetermined high threshold value to  
15 derive a first sum  $p$ ;

16 (v) a second adder for adding the Gaussian interpolation kernel values  $G(k-x')$  for all  
17 values of  $k$  where  $I(k)$  is greater than the predetermined low threshold value and less than the  
18 predetermined high threshold value to derive a second sum  $q$ ; and

19 (vi) a divider for deriving the estimated off-grid brightness value  $B(x')$  at the off-grid  
20 position  $x'$  received from the off-grid position generator.

1 136. The apparatus of claim 125, 128, 131 or 135, wherein the predetermined low  
2 threshold value is the noise level of a light-sensing element having a sensitivity level  
3 corresponding to the pixel position of the compensated on-grid brightness value being compared  
4 therewith compensated by the inverse of the response function of the light-sensing element, and  
5 the predetermined high threshold value is the saturation or near saturation brightness value of a  
6 light-sensing element having the sensitivity level corresponding to the pixel position of the  
7 compensated on-grid brightness value being compared therewith.

1 137. The apparatus of claim 123, wherein the pixel positions of the pixel position array  
2 provided by the second pixel position generator are located at respective regularly spaced pixel  
3 positions of a linear pixel position array, and the off-grid positions of the off-grid position array  
4 provided by the off-grid position generator are each located between a respective adjacent pair of  
5 pixel positions of the linear pixel position array.

1           138. The apparatus of claim 123, wherein the pixel positions of the pixel position array  
2 provided by the second pixel position generator are located at respective intersections of a  
3 plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the  
4 pixel rows being orthogonal to the pixel columns, and wherein the off-grid positions of the off-  
5 grid position array provided by the off-grid position generator are located at respective  
6 intersections of a plurality of regularly spaced intermediate rows and a plurality of regularly  
7 spaced intermediate columns, each intermediate row being parallel to the pixel rows and  
8 extending between a respective adjacent pair of the pixel rows and each intermediate column  
9 being parallel to the pixel columns and extending between a respective adjacent pair of the pixel  
10 columns.

1           139. The apparatus of claim 123, wherein the pixel positions of the pixel position array  
2 provided by the second pixel position generator are located at respective intersections of a  
3 plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the  
4 pixel rows being orthogonal to the pixel columns, and wherein the off-grid positions of the off-  
5 grid position array provided by the off-grid position generator are located at respective  
6 intersections of a plurality of regularly spaced intermediate columns and the pixel rows, each one  
7 of the intermediate pixel columns being parallel to the pixel columns and extending between a  
8 respective adjacent pair of pixel columns.

1           140. The apparatus of claim 137, 138 or 139, wherein the interpolator includes means for  
2           shifting the off-grid position array to coincide with the pixel position array, whereby the  
3           resampled on-grid brightness value at each pixel position of the pixel position array is equal to  
4           the estimated off-grid brightness value at a coincident off-grid position of the shifted off-grid  
5           position array.

1           141. The apparatus of claim 138, wherein the interpolator derives a respective resampled  
2           on-grid brightness value at a pixel position received from the second pixel position generator by  
3           computing the product of respective estimated off-grid brightness values at a predetermined  
4           number of off-grid positions that are nearest neighbors to the received pixel position and an  
5           interpolation kernel having the same dimensions as the predetermined number of off-grid  
6           positions.

1           142. The apparatus of claim 141, wherein the plurality of intermediate rows each extend  
2           medially between a respective adjacent pair of pixel rows and the plurality of regularly spaced  
3           intermediate columns each extend medially between a respective adjacent pair of pixel columns,  
4           and wherein the pixel positions provided by the second pixel position generator have coordinates  
5           (x,y) where x has values from 2.5 to xSize-2.5 and, y has values from 2.5 to ySize-2.5, xSize is  
6           the dimension of the captured image in the direction of the pixel rows and ySize is the dimension  
7           of the captured image in the direction of the pixel columns.

1           143. The apparatus of claim 142, wherein the interpolator is responsive to a pixel position  
 2           (x,y) received from the second pixel position generator for deriving a respective resampled on-  
 3           grid brightness value in accordance with the relation

$$I(x-2,y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x-1.5 + i, y-1.5 + j) \phi_{ij},$$

4           where  $I(x-2, y-2)$  is the resampled on-grid brightness value at pixel position  $(x-2, y-2)$ ,  
 5            $B(x-1.5+i, y-1.5+j)$  is the estimated off-grid brightness value at off-grid position  
 6            $(x-1.5+i, y-1.5+j)$ ,  $\phi_{ij}$  is the value of a  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices  $i$  and  $j$ , and  
 7           indices  $i$  and  $j$  each has values from 0 to 3.

1           144. The system of claim 123, wherein the pixel positions provided by the second pixel  
 2           position generator are located at respective intersections of a plurality of regularly spaced pixel  
 3           rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the  
 4           pixel columns, and wherein the off-grid positions provided by the off-grid position generator are  
 5           located at respective intersections of a plurality of regularly spaced intermediate rows and the  
 6           pixel columns, and at respective intersections of a plurality of regularly spaced intermediate  
 7           columns and the pixel rows, each one of the intermediate rows being parallel to the pixel rows  
 8           and extending medially between a respective adjacent pair of the pixel rows, each intermediate



column being parallel to the pixel columns and extending medially between a respective adjacent pair of the pixel columns, the pixel positions provided by the second pixel position generator having coordinates (x,y) where x has values from 2.5 to xSize-2.5, y has values from 2.5 to ySize-2.5, xSize is the dimension of the captured image in the direction of the pixel rows and ySize is the dimension of the captured image in the direction of the pixel columns.

145. The system of claim 144, wherein the interpolator is responsive to a pixel position received from the second pixel position generator for deriving a respective resampled on-grid brightness value in accordance with the relation

$$I(x-2,y-2) = \sum_{i=0}^3 \sum_{j=0}^3 B(x+0.5i-0.5j, y-1.5+0.5i+0.5j)\phi_{ij},$$

where  $I(x-2,y-2)$  is the resampled brightness value at pixel position (x-2, y-2),  $B(x+0.5i-0.5j, y-1.5+0.5i+0.5j)$  is the off-grid brightness value at off-grid position (x+0.5i-0.5j, y-1.5+0.5i+0.5j),  $\phi_{ij}$  is the value of a  $4 \times 4$  cubic interpolation kernel  $\phi$  at indices i and j, and the indices i and j each have values from 0 to 3.

1           146. The method of claim 128 or 143, wherein the  $4 \times 4$  cubic interpolation kernel  $\phi$  has  
2 the form:

3

4

5

6

|     |        |        |        |        |
|-----|--------|--------|--------|--------|
|     | 0.043  | -0.661 | -0.661 | 0.043  |
|     | -0.661 | 10.28  | 10.28  | -0.661 |
|     | -0.661 | 10.28  | 10.28  | -0.661 |
| j ↑ | 0.043  | -0.661 | -0.661 | 0.043  |
|     |        | i →    |        |        |

•

1           147. The apparatus of claim 141, wherein the interpolation kernel is a 2-dimensional  
2 Gaussian kernel.

1           148. The system of claim 147, wherein the 2-dimensional Gaussian kernel has the form:

2

3

4

5

6

7

|     |        |        |        |        |        |        |
|-----|--------|--------|--------|--------|--------|--------|
|     | 0.0037 | 0.0101 | 0.0166 | 0.0166 | 0.0101 | 0.0037 |
|     | 0.0101 | 0.0275 | 0.0452 | 0.0452 | 0.0275 | 0.0101 |
|     | 0.0166 | 0.0452 | 0.0743 | 0.0743 | 0.0452 | 0.0166 |
|     | 0.0166 | 0.0452 | 0.0743 | 0.0743 | 0.0452 | 0.0166 |
|     | 0.0101 | 0.0275 | 0.0452 | 0.0452 | 0.0275 | 0.0101 |
| j ↑ | 0.0037 | 0.0101 | 0.0166 | 0.0166 | 0.0101 | 0.0037 |
|     |        | i →    |        |        |        |        |

•

1           149. The system of claim 141, wherein the interpolation kernel is a bi-cubic B-spline  
2 interpolation filter kernel.

1            150. The system of claim 149, wherein the bi-cubic B-spline interpolation filter kernel  
2 has the form:

|   |        |        |        |        |
|---|--------|--------|--------|--------|
|   | 0.0043 | 0.0100 | 0.0100 | 0.0043 |
|   | 0.0100 | 0.2296 | 0.2296 | 0.0100 |
|   | 0.0100 | 0.2296 | 0.2296 | 0.0100 |
| j | 0.0043 | 0.0100 | 0.0100 | 0.0043 |
| i |        |        |        |        |

1            151. The apparatus of claim 141, wherein the interpolation kernel is a bi-linear  
2 interpolation filter kernel.

1            152. The system of claim 151, wherein the bi-linear interpolation kernel has the form:

|   |     |     |
|---|-----|-----|
|   | 0.5 | 0.5 |
| j | 0.5 | 0.5 |
| i |     |     |

1            153. The system of claim 137, wherein the off-grid positions provided by the off-grid  
2 position generator are each located midway between a respective adjacent pair of pixel positions  
3 of the linear pixel position array, the pixel positions provided by the second pixel position

generator having coordinate  $x$ , where  $x$  has values from 3.5 to  $xSize-3.5$  and  $xSize$  is the dimension of the captured line image.

154. The system of claim 153, wherein the interpolator is responsive to a pixel position received from the second pixel position generator for deriving a respective resampled on-grid position brightness value in accordance with the relation

$$I_o(x-3) = \sum_{k=-1.5}^{k=1.5} B(x+k)\psi(k),$$

where  $I_o(x-3)$  is the resampled on-grid brightness value at pixel position  $(x-3)$ ,  $B(x+k)$  is the estimated off-grid brightness value at off-grid position  $(x+k)$ ,  $k$  is a position of a  $4 \times 1$  cubic interpolation kernel  $\psi$ ,  $\psi(k)$  is the value of the cubic interpolation kernel  $\psi$  at position  $k$ , and the position  $k$  has values from  $-1.5$  to  $1.5$ .

155. The system of claim 154, wherein the  $4 \times 1$  cubic interpolation kernel  $\psi$  has the form:

|       |       |       |       |
|-------|-------|-------|-------|
| -0.96 | 13.44 | 13.44 | -0.96 |
|-------|-------|-------|-------|

1           156. A system for obtaining a relatively high dynamic range image of a scene using a  
2 relatively low dynamic range image sensor adapted to be exposed to incident light from the scene  
3 for capturing an image thereof comprising:

4           (a) an image sensor having a multiplicity of light-sensing elements in an array, each one  
5 of the light-sensing elements having a particular one of a plurality of sensitivity levels to incident  
6 light in accordance with a predetermined sensitivity pattern for the array of light-sensing  
7 elements and having a response function, each one of the light-sensing elements in response to  
8 incident light from the scene producing a captured image brightness value at a corresponding one  
9 of a multiplicity of pixel positions of a pixel position array, whereby each one of the multiplicity  
10 of pixel positions corresponds to a particular one of the plurality of sensitivity levels of the light-  
11 sensing elements;

12           (b) a captured image memory for storing respective captured image brightness values  
13 produced by the light-sensing elements at pixel positions of the pixel position array;

14           (c) a pixel position generator for providing the pixel positions of the pixel position array;

15           (d) an on-grid brightness value generator receiving the pixel positions from the pixel  
16 position generator and being responsive to a pixel position received from the pixel position  
17 generator for deriving from the captured image brightness values in the captured image memory  
18 a respective output image brightness value at the received pixel position, the respective output

image brightness value being derived from a corresponding plurality of captured image brightness values; and

(e) an output image memory for storing the respective output image brightness value at each pixel position received from the pixel position generator derived by the on-grid brightness value generator.

157. The system of claim 156, wherein the array of light-sensing elements of the image sensor is a two-dimensional array and the pixel position array is a linear array having regularly spaced pixel positions in a linear pixel position row.

158. The system of claim 156, wherein the array of light-sensing elements of the image sensor is a two-dimensional array and the pixel position array is a two-dimensional array having pixel positions located at respective intersections of a plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel columns, and wherein the pixel positions provided by the pixel position generator have coordinates (x,y), where x has values from 2.5 to xSize-2.5, y has values from 2.5 to ySize-2.5, and xSize and ySize are the dimensions of the captured image in the directions of the pixel rows and the pixel columns, respectively.

159. The system of claim 158, wherein the on-grid brightness value generator is responsive to a pixel position (x,y) received from the pixel position generator for deriving from the captured image brightness values in the captured image memory a respective output image brightness value at the received pixel position in accordance with the relation

$$I_o(x-2,y-2) = \sum_{i=0}^4 \sum_{j=0}^4 I_c(x-2 + i, y-2 + j)\phi_{ij},$$

where  $I_c(x - 2 + i, y - 2 + j)$  is the captured image brightness value at pixel position (x - 2 + i, y - 2 + j),  $\phi_{ij}$  is the value of an on-grid interpolation filter kernel  $\phi$  at indices i and j, indices i and j each have values from 0 to 4, and  $I_o(x - 2, y - 2)$  is the output image brightness value at pixel position (x - 2, y - 2).

160. A system for obtaining a relatively high dynamic range image of a scene using a relatively low dynamic range image sensor adapted to be exposed to incident light from the scene for capturing an image thereof comprising:

(a) an image sensor having a multiplicity of light-sensing elements in an array, each one of the light-sensing elements having a particular one of a plurality of sensitivity levels to incident light in accordance with a predetermined sensitivity pattern for the array of light-sensing elements and having a response function, each light-sensing element in response to incident light from the scene producing a captured image brightness value at a corresponding one of a

9 multiplicity of pixel positions of a pixel position array, whereby each one of the multiplicity of  
10 pixel positions corresponds to a particular one of the plurality of sensitivity levels of the light-  
11 sensing elements;

12 (b) a captured image memory for storing the captured image brightness values produced  
13 by the light-sensing elements at pixel positions of the pixel position array;

14 (c) a pixel position generator for providing the pixel positions of the pixel position array;

15 (d) an on-grid brightness value generator receiving pixel positions from the pixel position  
16 generator and being responsive to a pixel position received from the pixel position generator for  
17 deriving from the captured image brightness values in the captured image memory a respective  
18 on-grid brightness value at the received pixel position, the respective on-grid brightness value  
19 being derived from a corresponding plurality of captured image brightness values;

20 (e) a response function compensator for compensating the respective on-grid brightness  
21 value at each received pixel position derived by the on-grid brightness value generator by the  
22 inverse of a combined response function of the light-sensing elements to provide a respective  
23 output image brightness value at each pixel position received from the pixel position generator,  
24 the combined response function being the sum of weighted response functions of light-sensing  
25 elements having different ones of the plurality of sensitivity levels, each one of the weighted  
26 response functions being a response function of a light-sensing element having a respective one  
27 of the plurality of sensitivity levels multiplied by a predetermined weighting factor for the  
28 respective one of the plurality of sensitivity levels; and



29 (f) an output image memory for storing the respective output image brightness value at  
30 each received pixel positions provided by the response function compensator.

1 161. The system of claim 160, wherein the response function compensator comprises a  
2 lookup table memory storing data representing the inverse of the combined response function of  
3 the light-sensing elements, and a mapper receiving on-grid brightness values from the on-grid  
4 brightness value generator and being responsive to an on-grid brightness value at a pixel position  
5 received from the pixel position generator for deriving a respective index for the lookup table  
6 memory and providing a data value in the lookup table memory corresponding to the respective  
7 index, the data value being the output image brightness value at the pixel position received from  
8 the pixel position generator.

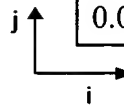
1 162. The system of claim 160, wherein the array of light-sensing elements of the image  
2 sensor is a two-dimensional array for capturing two-dimensional images, and the pixel position  
3 array is a two-dimensional array having pixel positions located at respective intersections of a  
4 plurality of regularly spaced pixel rows and a plurality of regularly spaced pixel columns, the  
5 pixel rows being orthogonal to the pixel columns, and wherein the pixel positions provided by  
6 the pixel position generator having coordinates (x,y), where x has values from 2.5 to xSize-2.5,  
7 y has values from 2.5 to ySize-2.5, and xSize and ySize are the dimensions of the captured  
8 image in the directions of the pixel rows and the pixel columns, respectively.

1           163. The system of claim 162, wherein the on-grid brightness value generator is  
 2 responsive to a pixel position received from the pixel position generator for deriving from the  
 3 captured image brightness values in the captured image memory a respective on-grid brightness  
 4 value at the received pixel position in accordance with the relation

$$I(x-2, y-2) = \sum_{i=0}^4 \sum_{j=0}^4 I_c(x-2 + i, y-2 + j) \phi_{ij},$$

5 where  $I_c(x - 2 + i, y - 2 + j)$  is the captured image brightness value at pixel position  
 6  $(x - 2 + i, y - 2 + j)$ ,  $\phi_{ij}$  is the value of a on-grid interpolation filter kernel  $\phi$  at indices  $i$  and  $j$ , the  
 7 indices  $i$  and  $j$  each have values from 0 to 4, and  $I(x - 2, y - 2)$  is the on-grid brightness value at  
 8 pixel position  $(x - 2, y - 2)$ .

1 164. The method of claim 159 or 163, wherein the on-grid interpolation filter kernel  $\phi$   
 2 has the form:

|   |   |        |        |        |        |
|---|---|--------|--------|--------|--------|
| 3 | 0.043   | -0.618 | -1.322 | -0.618 | 0.043  |
| 4 | -0.618  | 9.001  | 19.238 | 9.001  | -0.618 |
| 5 | -1.322  | 19.238 | 41.12  | 19.238 | -1.322 |
| 6 | -0.618  | 9.001  | 19.238 | 9.001  | -0.618 |
| 7 | 0.043   | -0.618 | -1.322 | -0.618 | 0.043  |
| 8 |  |        |        |        |        |

1 165. The system of claim 158, wherein the array of light-sensing elements of the image  
 2 sensor is a linear array for capturing a line image, and the pixel position array is a linear array  
 3 having regularly spaced pixel positions in a linear pixel row.

1 166. A system for obtaining a relatively high dynamic range image of a scene using a  
 2 relatively low dynamic range image sensor adapted to be exposed to incident light from the scene  
 3 for capturing an image thereof comprising:

4 (a) an image sensor having a multiplicity of light-sensing elements in an array, each one  
 5 of the light-sensing elements having a particular one of a plurality of sensitivity levels to incident  
 6 light in accordance with a predetermined sensitivity pattern for the array of light-sensing  
 7 elements and having a respective response function, each light-sensing element in response to  
 8 incident light from the scene producing a captured image brightness value at a corresponding one

9 of a multiplicity of pixel positions of a pixel position array, whereby each one of the multiplicity  
10 of pixel positions corresponds to a particular one of the plurality of sensitivity levels of the light-  
11 sensing elements;

12 (b) a captured image memory for storing the captured image brightness values produced  
13 by the light-sensing elements at pixel positions of the pixel position array;

14 (c) a first pixel position generator for providing the pixel positions of the pixel position  
15 array;

16 (d) a sensitivity pattern memory for storing data indicative of the sensitivity level  
17 corresponding to each one of the first pixel positions of the pixel position array;

18 (e) a response function compensator receiving pixel positions from the first pixel position  
19 generator, data indicative of the sensitivity levels corresponding to the received pixel positions  
20 from the sensitivity pattern memory and captured image brightness values at the received pixel  
21 positions from the captured image memory, and being responsive to a pixel position received  
22 from the first pixel position generator and data indicative of the sensitivity level corresponding to  
23 the received pixel position for retrieving from the captured image memory the captured image  
24 brightness value at the received pixel position and for compensating the retrieved captured image  
25 brightness value at the received pixel position by the inverse of the response function of a light-  
26 sensing element having the sensitivity level corresponding to the received pixel position to  
27 provide a respective compensated brightness value at the pixel position received from the first  
28 pixel position generator;

29 (f) a compensated on-grid brightness value memory for storing respective compensated  
30 captured image values at the pixel positions received from the first pixel position generator;

31 (g) a second pixel position generator for providing the pixel positions of the pixel  
32 position array;

33 (h) an on-grid brightness value generator receiving pixel positions from the second pixel  
34 position generator and being responsive to each pixel position received from the second pixel  
35 position generator for deriving from the captured image brightness values in the captured image  
36 memory a respective output image brightness value at each received pixel position; and

37 (i) an output image memory for storing the respective output image brightness value at  
38 each pixel position received from the second pixel position generator.

39  
40  
41 167. The system of claim 166, wherein the response function compensator comprises a  
42 lookup table memory storing separate lookup table data representing the inverse of respective  
43 response functions of light-sensing elements having different ones of the plurality of sensitivity  
4 levels, and a mapper receiving captured image brightness values from the captured image  
5 memory and being responsive to a captured image brightness value at a pixel position received  
6 from the first pixel position generator for deriving a respective index for the lookup table  
7 memory, and retrieving therefrom a compensated on-grid brightness value corresponding to the  
8 respective index from lookup table data representing the inverse of the response function of a  
9 light-sensing element having the sensitivity level corresponding to the received pixel position,

10 the retrieved compensated on-grid brightness value being provided to the compensated on-grid  
11 brightness value memory.

1 168. The system of claim 166, wherein the array of light-sensing elements of the image  
2 sensor is a two-dimensional array, and the pixel position array is a two-dimensional array having  
3 pixel positions located at respective intersections of a plurality of regularly spaced pixel rows and  
4 a plurality of regularly spaced pixel columns, the pixel rows being orthogonal to the pixel  
5 columns.

1 169. The system of claim 166, wherein the array of light-sensing elements of the image  
2 sensor is a linear array for capturing a line image and the pixel position array is a linear array  
3 having respective regularly spaced pixel positions of a linear pixel row, and wherein the pixel  
4 positions provided by the pixel position generator have coordinates  $x$ , where  $x$  has values from  
5 2.5 to  $xSize - 2.5$  and  $xSize$  is the dimension of the captured line image.

1 170. The system of claim 169, wherein the on-grid brightness value generator is  
2 responsive to a pixel position  $x$  received from the second pixel position generator for deriving  
3 from the captured image brightness values in the captured image memory a respective output  
4 image brightness value at the received pixel position, the on-grid brightness value generator  
5 comprising:

- 6 (i) a memory for storing a  $5 \times 1$  Gaussian interpolation filter kernel  $G$ ;
- 7 (ii) a comparator for comparing each one of five compensated on-grid brightness values
- 8  $I(k)$  at pixel positions  $k$  having values from  $x-2$  to  $x+2$  with a predetermined low threshold value
- 9 and a predetermined high threshold value;
- 10 (iii) a multiplier for calculating a quantity  $I(k)G(k-x)$  for each value of  $k$  at which  $I(k)$  is
- 11 greater than the predetermined low threshold value and less than the predetermined high
- 12 threshold value, where  $G(k-x)$  is the value of the Gaussian interpolation kernel  $G$  at position
- 13  $(k-x)$ ;
- 14 (iv) a first adder for adding the quantities  $I(k)G(k-x)$  calculated by the multiplier for each
- 15 value of  $k$  where  $I(k)$  is greater than the predetermined low threshold value and less than the
- 16 predetermined high threshold value to derive a first sum  $p$ ;
- 17 (v) a second adder for adding the values  $G(k-x)$  of the Gaussian interpolation kernel in
- 18 the memory for each value of  $k$  where  $I(k)$  is greater than the predetermined low threshold value
- 19 and less than the predetermined high threshold value to derive a second sum  $q$ ; and
- 20 (vi) a divider for deriving a respective output image brightness value  $I_o(x)$  at the position
- 21  $x$  received from the second pixel position generator by dividing the sum  $p$  by the sum  $q$ .

1 171. The system of claim 170, wherein the predetermined low threshold value is the  
 2 noise level of a light-sensing element having the sensitivity level corresponding to the pixel  
 3 position of the compensated on-grid brightness value being compared therewith compensated by

4 the inverse of the response function of the light-sensing element, and the predetermined high  
5 threshold value is the saturation or near saturation brightness value of a light-sensing element  
6 having the sensitivity level corresponding to the pixel position of the compensated on-grid  
7 brightness value being compared therewith.

1 172. The system of claim 170, wherein the  $5 \times 1$  Gaussian interpolator filter kernel has  
2 the form:

|     |     |      |     |     |
|-----|-----|------|-----|-----|
| 0.1 | 3.6 | 10.0 | 3.6 | 0.1 |
|-----|-----|------|-----|-----|

→  
k